RECLAMATION

Managing Water in the West

Summary Report for Geomorphic Assessment of Hoh River in Washington State

Hoh River Miles 17 to 40: Oxbow Canyon and Mount Tom Creek

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center

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River Miles 17 to 40 between Oxbow Canyon and Mount Tom Creek

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UNITED STATES DEPARTMENT OF THE INTERIOR

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1.0 SUMMARY AND CONCLUSIONS

This report presents a geomorphic reach analysis between river miles 17 to 40 (Oxbow Canyon to Mount Tom Creek) of the Hoh River (see figure 2 for study area location map, and Attachment 1 for photographic overview of watershed). Available data and analysis were sufficient to identify the historical channel migration zone (HCMZ) that represents a timeframe between 84 to 111 years before 2002 (see Attachment 2). The potential risk of additional lateral expansion along the HCMZ boundary was estimated to identify all of the areas along the HCMZ boundary that are likely to erode at some point in the future.

The risk categories were subdivided based on the timeframe in which the river might be expected to run against the HCMZ boundary and cause erosion. For example, actively eroding banks have the river running against them right now and may currently pose a threat to infrastructure or property during floods. Banks with a high risk are areas where the river is next expected to migrate or avulse to from its current position. Banks with a moderate risk may not see the river run against them until several years in the future, and could be considered to have a lower priority for management than the active and high risk banks. Banks with a low risk have not had the channel run against them since at least 1939 and this pattern would be expected to continue in the future. The rates that each bank might erode while the river ran against it were also estimated. These rates were estimated on the basis of historical erosion rates for boundaries composed of similar material between 1939 and 2002, and on the present vegetation and land use along the boundary and adjacent surfaces. Analysis of historical erosion rates along the HCMZ indicate that areas with logged terrace surfaces erode at a faster rate than areas with old growth vegetation.

The maximum lateral extent of future expansion of the HCMZ over the next few centuries was also delineated and is referred to as the future CMZ (Attachment 2). The delineated future CMZ is conservative in that the boundaries include more areas than could possibly erode in the next few centuries based on historical rates of erosion. However, a local area could experience accelerated rates of terrace bank erosion, so that the HCMZ boundary could reach the future channel migration boundary in less than a few centuries. The boundary of the future channel migration zone was delineated in most places along geomorphic features, such as terrace banks, bedrock outcrops, and valley walls. As the river encounters progressively higher terraces as it expands the HCMZ, the rate of further expansion could become slower than the historical rates. The lateral extent of the channel migration zone boundary in the Middle Hoh Reach is in some places limited because the river channel can only migrate so far before the slope becomes too low to convey water and transport sediment, at which time the meander bend will be cutoff. The prediction of the risk and rate of HCMZ expansion in the near future is less confident than the delineation of the HCMZ boundary. The future CMZ requires the greatest amount of judgment and has the least certainty. In some instances a road or other infrastructure may be protected if the river runs against it at some point in the future. If the protection were maintained, this would limit the expansion of the channel migration zone to the protected infrastructure rather than the future channel migration zone boundary delineated for this study.

Expansion of the HCMZ is a natural process for the Hoh River given its current physical setting, but there has been greater erosion in the Middle Hoh reach relative to the Park. Approximately 47 acres of erosion along the HCMZ has occurred within Olympic National Park and 276 acres has occurred in the Middle Hoh since 1939. Of the total area that has eroded since 1939, 86% (278 acres) was composed of alluvial material. The reason for the greater erosion area in the Middle Hoh relative to the Park can be attributed to changes in flood sizes, channel form, vegetation and woody debris, and human disturbance.

Higher magnitude floods can cause higher rates of channel migration and subsequently higher amounts of lateral expansion of the HCMZ, particularly if the floods are happening more frequently. A comparison of limited gage data and an evaluation of increase in drainage basin size in the downstream direction indicate that flood magnitudes in the Middle Hoh may be two to three times that of floods in the Park depending upon the contribution of runoff from the South Fork drainage. Based on two USGS gages that provide a record of discharge data near the study areas, the annual flood peaks and the frequency of floods equal to or greater than the 2-year flood have both increased on the Hoh River in the study area since 1927, the beginning of the period of record. Between 1927 and 1971 (44 years), the 2-year flood was exceeded between 18 and 50 percent of the years evaluated, but since 1971 it has been exceeded in greater than 70 percent of the years evaluated. In Reaches 7 and 8, the fastest rate of channel meander bend migration occurred during the period 1977 to 1981 when the 25-year flood was twice exceeded. This indicates the higher magnitude floods that are now occurring can cause greater rates of channel migration and subsequently greater amounts of lateral expansion of the HCMZ, particularly if the floods are happening more frequently. However, the largest total area of measured erosion along the HCMZ boundary occurred in Reach 8 between 1939 and 1960, prior to the increased flooding, where there was a meander cutoff that flowed head on into a terrace.

While high flows do initiate higher rates of channel migration and bank erosion, they are not the only factor causing higher rates of lateral expansion of the HCMZ in the Middle Hoh Reach. A change in channel form from multiple channels, a steeper slope, more woody debris, and higher roughness in most of the Park Reach to a channel form with a more sinuous channel, a flatter slope, less wood, and lower roughness in the Middle Hoh (except for Spruce Canyon) also plays a role, because the majority of erosion occurs along the outside of meander bends. Herrera Environmental Consultants (Herrera) found that the Park reaches have more woody debris in the active channel than the Middle Hoh reaches, which causes higher roughness values (written communication, 2004). In both Reaches 7 and 8, the upstream channel meanders have only been cutoff twice over the roughly hundred years of channel alignment documentation available. The cycle of meander bend migration and cutoff in Reach 5 is slightly faster than it is in the downstream Reaches 7 and 8. Channel changes within the Olympic National Park reaches are the most frequent of the eight study reaches, and the flow is often split into multiple channel paths by large woody debris and gravel bars. The HCMZ area reworked the most often in the last century within Olympic National Park has been in the middle of the HCMZ instead of at meander bends that coincide with the HMCZ boundary. This indicates that even when erosion occurs along the boundary within the Park reaches, the river is not likely to remain in that location very long. This means that the river channel in the Middle Hoh reaches continues to erode terrace banks for a longer period of consecutive time and causes the HCMZ boundary to expand at a greater rate than in the Park reaches.

Where there is less resistance along the outside of a meander bend in both the Middle Hoh and Park reaches, accelerated rates of erosion can occur. The main form of resistance is typically from large vegetation that provides substantial root cover for the portion of the exposed bank that is in contact with the river during floods. Additionally, large cobbles that are eroded from the bank often align along the toe of the bank, where they have been observed to limit expansion of the HCMZ in the Park Reach. Herrera found that in the Park, trees present on alluvial banks that have stem diameters greater than 21" erode more slowly from river processes and can remain stable when they fall into the river and help slow the rate of bank erosion (written communication, 2004). The reaches in Olympic National Park have less discharge than the reaches downstream from the confluence with the South Fork Hoh River, which would mean shallower water depths during floods in which to float the large woody debris. This may indicate that a larger diameter log is needed to remain stable in the river channel downstream from the South Fork confluence than upstream of it. The removal of riparian forest and large woody debris along the terraces in the Middle Hoh has reduced the amount of large woody debris that can be supplied to the channel, because old growth vegetation has been eliminated along the terrace banks of the HCMZ.

Measurements of natural erosion rates in the Middle Hoh were not possible, but by normalizing the changes in slope and discharge, erosion areas in the Park reaches could be used for comparison. All of the Middle Hoh areas where HCMZ expansion was measured since 1939 had been logged prior to the river running against the bank. Although prior to disturbance, the older cadastral survey maps did not have a clear definition of the terrace boundaries, and, therefore, could not be used to determine natural erosion rates of the Middle Hoh HCMZ. There are a few undisturbed erosion areas within the Park reaches that do have a single meandering channel eroding the alluvial terrace bank. These undisturbed areas were used to develop a natural rate of erosion for the Middle Hoh by normalizing the naturally occurring changes in discharge and slope between the two study areas. There are 14 comparable areas (4 within the Park reaches and 10 within Middle Hoh reaches) where an alluvial terrace bank was eroded along the outside of a meandering channel bend. For each of these 14 areas, the average erosion rate was computed over the period from 1939 to 2002 and normalized by the maximum erosion rate. The total stream power (2-year discharge multiplied by the average hydraulic slope) was computed for each reach and normalized by the maximum stream power. The normalized erosion rate was then divided by the normalized total stream power. Although there were several assumptions made for the input data, the computations indicate that on average half of the terrace bank erosion that occurred in the Middle Hoh reaches cannot be explained solely by changes in discharge, channel planform, or longitudinal slope. This indicates that logging of the alluvial terrace surfaces bounding the HCMZ has resulted in an additional amount of erosion in the Middle Hoh that otherwise would not have occurred.

The consistency of the river planform through the Middle Hoh reaches indicates that the sediment transport capacity of the Hoh River is generally in balance with the upstream sediment supply. The increases in coarse sediment supply to the Middle Hoh reaches has not been great enough to cause changes in river planform. There is a gradual reduction in slope in the downstream direction of the study area, which could cause a gradual reduction in transport capacity in the downstream direction. However, this appears to be balanced by the increase in river flow from downstream tributaries, especially the South Fork Hoh River. Visual observations confirm that sand to cobble-sized sediment is transported through all study reaches and even to the river mouth. Sensitivity testing of stream power (the balance of water flow or velocity and channel slope) indicated that the transport capacity of the Park reaches is nearly equivalent to the Middle Hoh reaches. The exception is Reach 6, through Spruce Canyon, which has higher sediment transport capacity than any of the other study reaches because it is constricted by bedrock on either side of the river. Stream power analyses help support the conclusion that the increases in coarse sediment loads from mass wasting and terrace bank erosion are likely small relative to the total sediment transport capacity.

Once delivered to the Hoh River, larger fine sediment loads could increase suspended sediment concentrations and turbidity over natural levels, but would not cause aggradation in the main channel. While fine sediment is easily transported downstream by the river, in areas of slow velocity, such as the forested floodplain and side channels, some of the suspended sediment could deposit, which may adversely impact aquatic habitat, especially when deposition occurs in side channels. Some recent studies of side channel sediment composition support this, but the longevity of the impact in relation to frequency of logging-induced mass wasting events is not known.

Several additional studies were recommended in the main report that would build upon the work accomplished for this study. Collection of Lidar data to document the existing topography of the valley floor and monitoring of future channel position and terrace bank erosion were among the recommendations. Additionally, further study of human impacts to tributary channels and integration of habitat data in the HCMZ area to information generated in this study could be helpful for further understanding the present and historical extent of habitat.

2.0 BACKGROUND

The Hoh River is a gravel- and cobble-bed stream located on the Olympic Peninsula of northwestern Washington State (figure 1 and Attachment 1). Management of infrastructure and property located along the river corridor has provided a challenge in the past due to the dynamic nature of the river. As recently as October 2003 major flooding resulted in erosion along the Park and County Roads and several areas of private property along the river. Biologists have questioned the impacts of human activities, particularly bank armoring and logging, on the salmonid and bull trout species (Hatten, 1991; Brenkman and Meyer, 1999). The question has been posed as to whether human activities may have altered and, in some areas, accelerated the natural physical river processes having an adverse affect on fisheries and bank erosion rates along the river corridor.

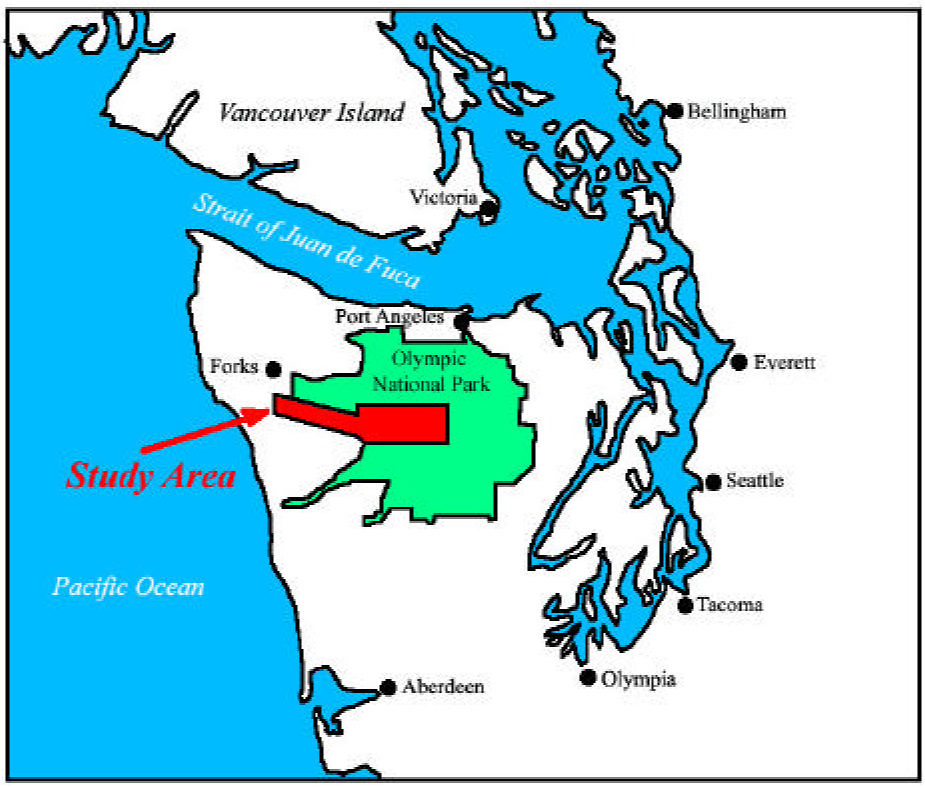

Figure 1. Location map of Hoh River study area.

2.1 Study Area

This report describes hydrologic and geomorphic studies along a section of the Hoh River, between river miles (RM) 17 and 40, in western Washington (figure 2). The study area includes two contrasting sections: one within Olympic National Park between RM 31 and RM 40 that has had relatively little human activity along the river corridor (Upper Hoh or Park), and a section outside the Park between RM 17 and RM 31 that over the last century

Figure 2

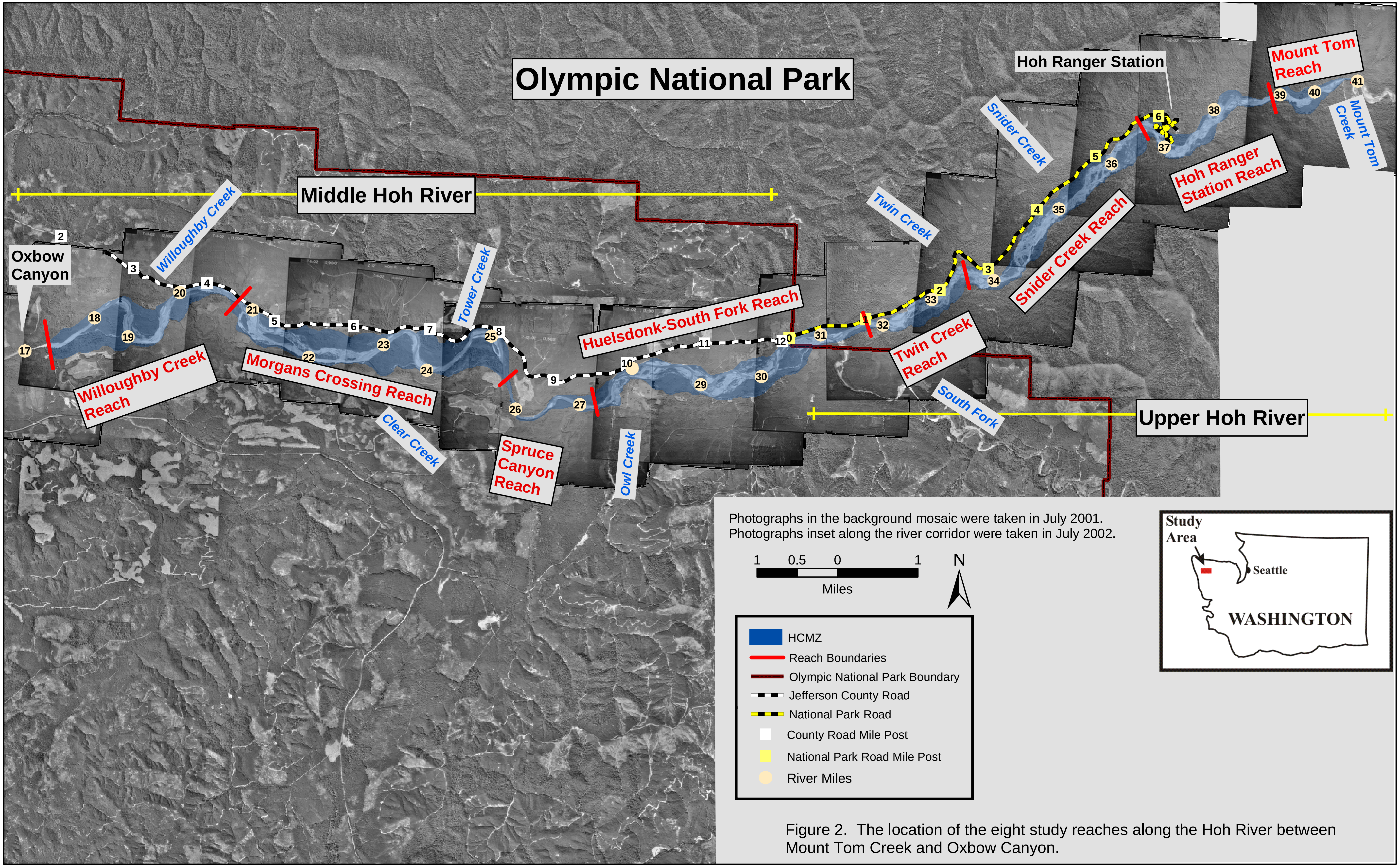

Figure 2. The location of the eight study reaches along the Hoh River between Mount Tom Creek and Oxbow Canyon.

has had more intervention by humans (Middle Hoh). Similar geomorphic analysis has already been conducted between RM 17 to the mouth of the Hoh River by Perkins and TerraLogic GIS (2004) and by Herrera Environmental Consultants and Northwest Hydraulic Consultants (2002).

2.2 Study Objectives

In 1998, the Hoh Tribe requested that a geomorphic study be undertaken by the Bureau of Reclamation (Reclamation) to better understand the existing and historical channel processes on the Hoh River and the possible impacts of human activities on these processes. Additionally, Olympic National Park (Park) and Jefferson County expressed an interest in knowing the potential for future river migration and bank erosion in the vicinity of critical infrastructure and property. A better knowledge of river processes is needed to meet both of these requests. It will also allow future management decisions regarding the maintenance of human infrastructure and property, land use, and the restoration of salmonid and bull trout habitat to be made with consideration of the broader impacts of these decisions over time and throughout the river system.

The first objective of this study was to identify the present and long-term characteristics of the study reach and to infer the present and long-term river processes. Characteristics along the length of the study reach were compared to detect similarities and differences in river processes along the river and over time. Because human activities since the early 1900s, which include logging, road building, and clearing of riparian vegetation and large woody debris, have been more prevalent outside of Olympic National Park than within it, we compared the characteristics and processes in the section of our study reach inside the Park to those of the section outside of the Park.

Because differences in river processes were identified between the study sections within and outside of Olympic National Park, our second study objective was to determine if the differences are related to differences in hydrology and geologic features, to human activities, or to a combination of both. In addition, we tried to determine if human activities adversely impact the rate and extent of terrace bank erosion or the quality of aquatic habitat.

The third objective of our study was to provide information that can be used for decisions regarding habitat restoration projects and management of infrastructure and property along the Hoh River. Resource managers were interested to know if all portions of the existing roads and infrastructure would eventually be subject to future erosion by the river, and hence become a management concern, or if not, what areas were most likely to be eroded. Some additional information is provided on a general scale regarding possible alternatives for dealing with areas impacted by river erosion.

2.3 Study Approach

To meet the three study objectives, an assessment of the historical, present, and possible future channel processes and natural or human-induced influences on these processes was needed. This is possible if long-term changes in the watershed (both natural and human-induced) are known, and the river system's adjustments to these changes are known. Because changes in water, sediment, wood debris, and slope are compensated by changes in the channels and floodplain, long-term stability can be assessed indirectly by looking for historical changes and trends in channel planforms (e.g., channel pattern), river migration, hydrology, sediment transport capacity, and the presence or absence of stable vegetated areas within the floodplain. These characteristics need to be measured or inferred over a time period that is long enough to assess the long-term stability of the channels and floodplain, so that future changes and possible responses in the river system can be inferred with some confidence. The characteristics also need to be assessed along a sufficient length of the river in order to detect any natural or human induced controls on the system.

Because direct observation of river processes was not possible over any period long enough to assess long-term stability or instability of the river system, we interpreted the channel and floodplain characteristics and changes from a sequence of historical photographs and maps, which provide a snapshot of channel conditions at a single time. Historical aerial photographs at about 10-year intervals between 1939 and 2002 were examined and supplemented by cadastral survey maps completed in 1891, 1895, or 1918. The cadastral survey maps were found to be generally accurate and rectified well with the historical aerial photography. These early maps (1891, 1895, and 1918) are believed to represent the river channel position and alignment under fairly natural conditions when there was only limited logging or human activity associated with homesteads that would impact river processes. Present channel and floodplain conditions were assessed from the most-recent aerial photographs (2002), from a river survey conducted in the spring of 2000, and from field observations made in the summers of 2000 and 2002. Future predictions of river behavior were inferred based on the observations made from the historical aerial photography and maps, and understanding of the physical influences and limitations on the river.

We used our mapping of historical channels since the late 1800s to identify control areas that have remained essentially unchanged (not eroded). These areas were used as boundaries to identify eight distinct geomorphic reaches between Mount Tom Creek near RM 40 and Oxbow Canyon near RM 17. At Spruce Canyon and Oxbow Canyon, the reach boundaries are formed by bedrock and are expected to remain stable for a long time. It is not known why the other reach boundaries have remained stable over the period of record. The river alignment upstream and downstream of each control is considered to be independent of each other. Similarly, localized human activities may affect channel position in one reach but would not necessarily impact channel position in another downstream reach. However, human activities that impact sediment supply or woody debris recruitment in an upstream reach could affect downstream reach geomorphology. Subsequently, we assessed characteristics such as sediment and wood supply and transport, slope, discharge, and land use separately for each reach, and then compared and contrasted these properties among the individual reaches over the period of the available historical record.

On time scales of a few decades in which management decisions are typically made, the active channels and adjacent floodplain of the Hoh River will be restricted within the entire river valley. This zone was identified using historical documentation and is referred to in this study as the historical channel migration zone (HCMZ). The HCMZ can be bounded by terraces and glacial banks, or material more resistant to erosion such as bedrock, alluvial fans, or human-placed bank armoring. The HCMZ typically contains frequent high flows, but less common large floods may overtop the banks of the HCMZ and inundate additional area of land. It represents the area where the majority of coarse sediment (sand, gravel, and cobbles) and woody debris is either currently being transported (active channel) or has been transported during the period of observed record (historical active channel paths).

Expansion of the HCMZ is a natural process that is influenced by the hydrology, river and floodplain characteristics, potential for erosion of the HCMZ banks, and human activities. Although a natural process, it is important to understand the potential for expansion because it can cause a loss of land and infrastructure, and at times endanger the safety of humans when infrastructure such as roads are placed alongside it. The HCMZ also provides aquatic habitat that is utilized by salmonid and bull trout species, so changes in the characteristics within this area can affect the amount and quality of habitat. In order to predict the rate and extent of possible future expansion of the HCMZ, historical expansion of the HCMZ was measured and characterized over the period of record. Additionally, geomorphic characteristics of the river, floodplain, and valley were considered in this prediction.

2.4 Study Tasks

The identification of watershed characteristics, the mapping of the historical channels, the determination of reach boundaries, and the delineation of the HCMZ helped us satisfy the first study objective, which was to identify the present and long-term characteristics and processes. Characteristics that we investigated and compared among the eight study reaches were channel form (sinuous, braided, etc), river channel migration and reworking of the active floodplain within the HCMZ, stable areas where the channel has not migrated within the HCMZ, flood history, erosion along terrace banks that bound the HCMZ, and the general capacity of the river to transport sediment and large woody debris within the HCMZ.

We compared the characteristics listed above for the four reaches that are within Olympic National Park with those for the four reaches outside of the Park to see if there are any similarities or differences. Possible reasons for any differences identified, especially the marked difference in human activities within and outside of the Park, were evaluated as part of the second study objective. The human activity that has been the most widespread in the vicinity of river processes was identified as logging of large, old growth trees within and near the HCMZ and on the slopes of the Hoh River valley.

The influence of woody debris on the river channel processes was investigated by Herrera and integrated into Reclamation's analysis (2004, in progress). To determine the relationship between logging and channel processes, evidence for logging of large mature trees on terraces immediately adjacent to the HCMZ boundary was explored for the Middle Hoh. It was of interest to determine whether the areas where large trees have been removed experienced accelerated river migration or bank erosion along the boundaries of the HCMZ, which could create instability in the HCMZ boundary and would provide additional sediment to the river system. Herrera investigated the size and presence of old growth forest patches in the Park Reach relative to where stable log jams and snags were present in the active channel that could influence channel form. The presence of large woody debris in the active channel in the Park Reach was then compared to the Middle Hoh Reach. This information was utilized to evaluate the influence of large trees on the rates of channel migration along the HCMZ boundary.

Historical river flow data from two nearby USGS gauging stations were investigated for any evidence of increasing or decreasing flood magnitudes or recurrences and compared to the occurrence and rates of historical river migration and bank erosion. The relative contribution of flow from drainage basins within the study reach was investigated to evaluate how the increase in flow may balance changes in river slope and influence sediment transport capacity. In particular, the largest tributary of the Hoh River, the South Fork drainage, enters very near the boundary between the Upper and Middle Hoh reaches.

Mass wasting and bank erosion are two processes by which additional sediment is supplied to the Hoh River. If the sediment supplied overwhelms the transport capacity of the river, it can impact the river morphology. Parks (1999) discovered a dramatic increase in the density of areas of mass wasting in the Middle Hoh Reach, outside of Olympic National Park, between 1939 and 1998. To determine if the Park Reach had experienced the same phenomenon, the number of areas of mass wasting on slopes in the Park between 1939 and 2001 were investigated. Expansion of the HCMZ would also contribute sediment to the river, and as mentioned earlier was measured over the period of record. In addition to evaluating the potential for an increase in sediment supply, the type of sediment that might be added to the river system and its affect on the river system based on the capacity of the river to transport additional sediment and large woody debris were investigated.

To meet the third study objective of applying our understanding of existing and historical river processes to management considerations, the risk of expansion (or erosion) along the HCMZ boundary in the near future was predicted. Risk of expansion was identified by looking at the likelihood that the river would migrate against the HCMZ boundary, and the potential for erosion of the HCMZ boundary. Both characteristics were identified on the basis of past river position, areas of historical erosion, a general characterization of the HCMZ bank material and vegetation along the surface, and areas where erosion has possibly been accelerated by the logging of large trees adjacent to the HCMZ boundary (see main report for a more detailed explanation). Additionally, the maximum possible extent of future erosion over a much longer time scale of a few centuries was also predicted by assessing historical erosion rates and locations, and natural and human induced geomorphic limitations.

2.5 Report Organization

This summary report is a condensed version of the main report. It is provided for those who want an overview of the entire report. The first portion of the summary report includes brief descriptions of the methods and main conclusions from all major aspects of our study. Because addressing management concerns is the reason that our study was initiated, the latter portion of the summary report discusses these management issues in some detail. The summary report also includes two attachments. Attachment 1 is a photographic overview of the watershed from the mouth of the Hoh River to the glaciers at the upstream end of the drainage basin. Attachment 2 includes the historical low-flow channels for each reach and shows the historical channel migration zone, the estimated risk and rate of possible future erosion along the boundaries of this zone, and the possible extent of a future channel migration zone for each reach.

The main report and accompanying appendices, which are provided on the CD in the back pocket, include the details of our study methodology, data collection, analyses, conclusions, and the application of our studies to management concerns. The organization of the main report is noted on the attached CD in the introduction section.

2.6 Acknowledgements

Many individuals and organizations contributed to this study by providing data, information, personal experiences on the river, and suggestions on study direction. Jill Silver, the regional biologist for the Hoh Tribe, was a wonderful source of knowledge about the Hoh River and was involved in the initial effort to get the study going. Biologists at the Hoh Tribe have generously shared data and knowledge about fish habitat on the river. Dr. Tim Abbe and staff of Herrera were active participants and provided analysis of the wood debris component in the Hoh River system and technical review of portions of our analysis that related to the woody debris assessment. The staff at Olympic National Park and Jefferson County participated in many aspects of the study providing historical data for the reaches in the Park and meeting rooms for the presentation of study results. In particular, Shelly Solomon, with Jefferson County, and Sam Brenkman, with Olympic National Park, were actively involved throughout the study. We would also like to thank Bill Baccus at Olympic National Park for his time and assistance in changing film each week during the time-lapse photography project. Sue Perkins, of Perkins GeoSciences provided her knowledge and experience on the Hoh River and reviewed an early version of this report. Dave Parks, of the Washington Department of Natural Resources, provided helpful insight to the mass wasting processes in the Middle Hoh based on his previous geologic work for the Hoh River Watershed Analysis.

We thank the many private landowners that have provided accounts of present issues and historical occurrences on the river. John England from the Flood Hydrology Group at the Technical Services Center in Reclamation provided a hydrologic analysis that was integrated into many sections of this Summary Report and the Main Report. Portions of his report (England, 2003) are referenced in Section 4 of the Main Report, and the full hydrology analysis has been separately published and is on the CD in the back pocket. A Reclamation survey crew from Ephrata, Washington, field office spent a week in torrential rain on the river to help us complete a survey of the river channel. Finally, we would like to thank Richard Link, Dan Levish and Ralph Klinger from Reclamation for their input and peer review of this study.

3.0 DESCRIPTION OF GEOMORPHIC STUDY REACHES

Of the eight reaches identified, the four upstream reaches are within Olympic National Park and the four downstream reaches are in the Middle Hoh (see Attachment 2). The Park Road follows the length of the right HCMZ boundary in the Park, and a campground is present in the upper part of the reach that is partially within the HCMZ. The left side of the HCMZ in the Park does not have any infrastructure or development along it. Along the Middle Hoh Reach, both sides of the river are developed and include private property, a major County Road on the right side, and infrastructure. The first white settlers in the Middle Hoh arrived in the late 1800s and began clearing land for homesteads.

3.1 Mount Tom Reach

The Hoh River in the Mount Tom Reach flows in a narrow, steep-walled valley. The historical channel migration zone (HCMZ) takes up nearly the entire valley floor. The steep valley walls are defined by rock, talus, and steep alluvial-fan deposits. The alluvial fan deposits contain gravelly sediment (pebbles, cobbles, and boulders) forming the HCMZ boundary, and its position has not changed since at least 1939.

3.2 Hoh Ranger Station Reach

The valley and HCMZ widen in the Hoh Ranger Station Reach. The average active channel width increases from 380 to 490 feet. The HCMZ in the upstream portion of the reach is bounded by alluvial-fan deposits, and the HCMZ in the downstream portion is bounded by alluvial banks. The active channel width is nearly equivalent to the width of the HCMZ, and is composed of multiple low-flow channels. A large amount of wood is present in the active channel in this reach. In the lower portion of the reach, the Olympic National Park Ranger Station and Rainforest Campground have been constructed on the right bank, both within and outside of the HCMZ (figure 3). The largest modification to the HCMZ is evident in the 1977 aerial photographs, where a historical channel path was blocked off by a campground road, thus effectively constricting the HCMZ.

Figure 3. Looking upstream at armored bank and engineered fish passage created at outlet of Taft Creek and a portion of the Rainforest Campground. The banks visible in this photograph are within the HCMZ. Armoring and fill operations have cut off historical channel paths and constricted the HCMZ in this area. Photograph taken by Reclamation in August 2002.

3.3 Snider Creek Reach

The 2.9-mile-long, straight active channel characterizes the Snider Creek Reach. Snider Creek drainage enters the main channel on the right side of the valley in the middle of the reach. Based on historical analysis of aerial photography, the low-flow channels are dynamic and the relative amounts of flow in each channel are variable. Because of a persistent point on the left HCMZ boundary at the upstream end of the reach, the channels have been directed toward the left side of the HCMZ in the upstream portion of the reach leaving persistent gravel bars on the right side. Since 1939, the HCMZ boundaries have been nearly stable.

3.4 Twin Creek Reach

Glacial deposits form a ridge about 3.5 km (2.3 mi) long along the right side of the HCMZ at the upstream end of this reach. This ridge consolidates tributary flow into Twin Creek and directs it into the Hoh River at the upstream end of the ridge. The ridge also limits the migration of the HCMZ to the right. The restriction of channel movement affects the downstream location of active channels and the HCMZ within the reach, and has resulted in fairly stable active channels since 1939. As a result, the HCMZ boundaries have been stable, and only a relatively small amount of lateral erosion of the boundaries has occurred.

The Olympic National Park Road roughly follows the right HCMZ boundary. The Olympic National Park road may restrict the translation of meanders at the upstream end of the reach. However, the HCMZ boundary is so close to the valley side that meander movement would be restricted naturally in about this same location. Even though future erosion of the HCMZ boundary is expected to be minimal, small amounts of erosion could jeopardize the road in places where it is close to the boundary. The section of road along the ridge of glacial deposits is particularly vulnerable to erosion. The Park Road has already been setback to the valley edge in two places near MP 1.5 and 1.7 due to the road being too close to the edge of the HCMZ where river erosion was making travel on the road unsafe (figures 4 and 5).

Figure 4. Looking downstream at section of Park Road near MP 1.7 in October 2000. Photograph courtesy of Olympic National Park.

Figure 5. Looking at same section of Park Road shown in Figure 4 in May 2001 following setback of road.

3.5 Huelsdonk-South Fork Reach

In the Huelsdonk-South Fork Reach the valley and HCMZ both widen noticeably relative to the upstream Park reaches. The valley between bounding rock ridges was filled with glacial and alluvial sediments that were subsequently incised by the Hoh River. Thus, the boundaries of the HCMZ commonly are composed of easily erodible glacial and alluvial deposits rather than the bedrock, colluvium, and steep, coarse alluvial-fan deposits that are present in the reaches upstream.

Tributaries in the Middle Hoh often flow across fairly flat terrace surfaces between the valley walls and the Hoh River. The coarse sediment being transported down the tributary channels often is deposited along the terrace surfaces before it can reach the Hoh River. This is in contrast to the Park Reaches where only narrow, if any, terraces exist between the valley and the river. The largest tributary to the Hoh River, the South Fork, enters the main channel on the left side near RM 31 at the upstream end of the Huelsdonk-South Fork Reach. Contributions of discharge and sediment from the South Fork influence the characteristics of the active channel and floodplain downstream of the confluence.

Overflow channels are common in this reach (figure 6). These channels may receive water only through groundwater connections during low flow periods, but they may convey a portion of flood flows at higher discharges. These channels often have woody debris throughout them which can create small backwater pools.

Figure 6. Looking downstream into overflow channel just downstream of confluence with South Fork along left side of HCMZ. Photograph taken by Reclamation in August 2002.

The boundary of Olympic National Park traverses the valley at the upstream end of this reach. Outside of Olympic National Park, Lewis Ranch and Huelsdonk Ranch were homesteaded by the early 1900s which resulted in clearing of old growth trees on terrace surfaces (figures 7 and 8). The area on the right side of the river just across from the South Fork confluence has the Park and County roads running alongside and partially within the HCMZ. This area of road has had recurrent river erosion problems since at least 1950. On the left side at the upstream end of the reach (just downstream of confluence with the South Fork), some early development also occurred which is evident in the 1950s aerial photography.

Figure 7. Looking upstream at right bank of river where the County and Park Roads and a portion of Lewis Ranch have been armored within the HCMZ to protect them from further erosion. Photograph taken in March 2002.

Figure 8. Huelsdonk Ranch is a historical homestead that is located along the left side of the HCMZ in Reach 5. Photograph taken in August 2002.

3.6 Spruce Canyon Reach

In most of the Spruce Canyon Reach, the HCMZ is confined by bedrock. The HCMZ is composed of a single active channel and a few small gravel bars. The HCMZ boundaries have not changed since at least 1939 in this reach.

3.7 Morgan's Crossing Reach

The upstream end of the Morgan's Crossing Reach is the mouth of Spruce Canyon. Flow entering into this reach is directed to the right side of the valley by the orientation of the outlet of Spruce Canyon. At this point, the HCMZ boundary coincides with the right valley wall and further migration is limited. These restrictions on meander migration affect the location and configuration of the active channel downstream in this reach.

In 1939 this reach had a wide, straight active channel. Since 1950, the upstream half of the reach has had a significantly narrower active channel that has been fairly sinuous. The downstream half of the reach has been fairly straight along a high bank composed of glacial deposits on the left side of the HCMZ.

Clear Creek Side Channel is the largest side channel in this reach. It is located along the left side of the HCMZ and has a large log jam at the entrance that limits the amount of surface flow and sediment that can enter. The side channel also receives flow from an un-named tributary.

The County Road parallels the right HCMZ boundary in several places in this reach. The downstream half of the meander bend (in the upstream portion of the reach) is pinned along the County Road near MP 6.7 by rock armor that has been placed to protect the road (figure 9). Erosion is currently occurring at the upstream end of the bank at County Road MP 6.7 and along the road at MP 7.7. A high glacial bank on the left side of the HCMZ has glacial-lacustrine deposits that repeatedly slump into the Hoh River (figure 10).

Figure 9. Looking downstream at County Road MP6.7 where armoring has been placed to prevent further erosion. A log jam constructed by the County is visible on the right side of the photograph. Photograph taken in August 2002.

Figure 10. Looking upstream and across at high glacial bank located in the downstream half of Reach 7 along the left side of the river. Photograph taken in August 2002.

3.8 Willoughby Creek Reach

Two terraces at the upstream end of the reach have remained stable since at least 1939, and likely since at least 1891 based on the old survey maps. One is on the right side between RM 20 and RM 21 where the HCMZ boundary coincides with the valley wall; the other is on the left near RM 19.5 just upstream of a long section bounded by unstable glacial-lacustrine deposits. In addition, the downstream end of the HCMZ is pinned where the Hoh River enters Oxbow Canyon. A large side channel, Elk Creek, is located on the left side of the present main channel (figure 11). Elk Creek has a surface water connection with the main channel and also receives additional flow from drainages to the left of the river. Willoughby Creek drainage enters this reach along the right side of the river.

Figure 11. Elk Creek Side Channel in Reach 8 has a significant surface water connection with the main channel. Photograph taken by Reclamation in August 2002.

4.0 HYDROLOGIC CHARACTERISTICS

The Hoh River Valley has a maritime climate with moderate temperatures and heavy precipitation (Hatten, 1991). At three locations evaluated by England (2003), the annual mean precipitation ranged from 94 to 125 inches. The majority of precipitation falls between November and April, which contributes to the occurrence of winter floods and subsequent channel changes on the Hoh River. The driest period typically occurs in August, when snowmelt is a dominant source of runoff for the Hoh River.

The frequency and magnitude of floods on the Hoh River are one of the major causes of the rate and extent of channel changes that occur. The most recent floods on the Hoh River occurred on January 7, 2002, which had a peak of 45,900 ft^3/s, and on October 17, 2003, which has a peak of 47,100 ft^3/s (provisional data at USGS Highway 101 gage located slightly downstream of Reach 8). These floods are between the 10-year and 25-year return periods. The highest peak flow recorded at the U.S. Highway 101 gage was 54,500 ft^3/s on November 24, 1990, and the lowest mean-daily flow recorded was 252 ft^3/s. Some limited gage data on the South Fork and the Hoh River at the Mount Tom Creek confluence (RM 40) indicate that flood magnitudes in the Middle Hoh Reach may on the order of 2 to 3 times that of those in the Park Reach.

The annual flood peaks and the frequency of floods exceeding the 2-year flood have increased since 1971. Between 1927 and 1971, the 2-year flood was exceeded between 18 and 50 percent of the years evaluated. However, since 1971, the 2-year flood has been exceeded in greater than 70 percent of the years evaluated. The causes of the increases in flood frequency and magnitude are unknown. Study findings indicate that some of the largest channel migration rates occurred when the increase in flood magnitudes began to occur. However, the largest amount of terrace bank erosion and expansion of the HCMZ occurred during 1939 to 1971, prior to the increase in magnitude and occurrence of floods.

5.0 WOOD IN THE HOH RIVER SYSTEM

There is an abundant source of large woody debris within Olympic National Park, because the steep forested slopes are relatively close to the active channel and because logging has not occurred (the Rainforest Campground area has had some human impacts). On the contrary, the terrace surfaces in the Middle Hoh have been logged at least once since 1939 and presently provide limited sources of large woody debris comparable to sizes in the Park. Herrera found that currently there is a greater amount of large woody debris within the HCMZ (relative to the active channel area) in the upstream Park Reach than in the Middle Hoh Reach (written communication, 2004). The large woody debris in the Park increases channel roughness and water depth, and generally reduces the river velocity and sediment transport capacity. The large woody debris also helps to create a more complex channel pattern, because flow is divided and diverted around log jams and large pieces of wood. The large woody debris is believed to have a greater influence in the four upstream reaches, because there is a greater source of large trees within Olympic National Park and because river flows and water depths are less in the reaches upstream of the South Fork confluence.

When evaluating roughness caused by large woody debris, Herrera also found significant temporal patterns. Inside the ONP roughness has increased up to 30% from 1950 to 2002, and outside ONP roughness has decreased a minimum of 30% (written communication, 2004). Downstream from the South Fork confluence, the river flows tend to be greater, so that single pieces of wood require a larger diameter to remain stable than they do in the upstream reaches. In contrast to the upstream four reaches, the majority of flow is often concentrated into a single channel, so the transport capacity for wood increases. Furthermore, there is a limited source of large woody debris in the reaches outside of Olympic National Park, where surfaces adjacent to the HCMZ have been logged at least once during the last century.

At the present time, the only source of large woody debris in the Middle Hoh is logs that get transported in from the Park Reach. At 10 sites evaluated by Herrera (2004) in the Park Reach, large woody debris eroded by the river was found to form snags and log jams within 50 m of where the large trees had been eroded. This indicates that the largest woody debris with the potential for forming snags or log jams in the Middle Hoh may typically remain in the Park Reach, and that only smaller wood gets transported into the Middle Hoh. With fewer and smaller pieces of large woody debris present in the four downstream reaches, the channel has less roughness and complexity than it does in the four upstream reaches.

In the Middle Hoh, woody debris can be found within the HCMZ along the outsides of meanders, on gravel bars, and at the entrances to side and overflow channels. The wood along the outsides of meanders and on the gravel bars are small relative to the old growth in the Park and can typically be easily transported during bankfull and larger floods. While limited in number relative to the Park Reach, log jams that do form may be maintained for several years and limit the migration of the main channel into the side and overflow channels. These log jams may either become vegetated and evolve into stable surfaces or be removed during high flows.

6.0 CHARACTERIZATION OF CHANGES IN CHANNEL POSITION AND FORM SINCE 1939

Characterizing the historical channel form in each reach helps to better understand the rates and patterns in which channels have changed in the past and how they may change in the future. It provides indications of whether natural processes and human activities limit or accelerate rates of channel and floodplain change, and how aquatic habitat and expansion of the HCMZ may be impacted by the changes. Channel form can be evaluated by looking at sinuosity, active channel width, channel slope, meander migration, and patterns of deposition and transport of sediment and woody debris.

6.1 Channel Patterns and Sinuosity

There are a few small areas within the Park that have a single meandering channel pattern. The remaining area in the Park has a relatively straight, steep, and constricted channel within a narrow valley where the channel repeatedly reworks its gravel bed in a narrow zone that leaves vegetated areas primarily along the edges of the HCMZ. For three of the four downstream reaches in the Middle Hoh, a single threaded meandering channel generally persists with a flatter slope and a wider valley. Spruce Canyon is the exception because it is confined by bedrock on either side of the river. For the more sinuous reaches, the upstream-most meander bend plays a large role in controlling the position of the channel for the remainder of the reach, until it has to pass through the next geologic control (reach boundary). The two downstream-most reaches (the Morgan's Crossing and Willoughby Creek Reaches) have consistently exhibited the most sinuous active channel of the eight study reaches since 1939. However, immediately following a meander cut off the active channel in these reaches is temporarily straight before a more sinuous meander pattern is reestablished. The exception is in the downstream half of the Morgan's Crossing Reach, the channel has been running relatively straight along the HCMZ ever since it was directed into a high glacial bank in the 1990s.

6.2 Active Channel Widths

The active channel is the area where the majority of coarse sediment and woody debris is transported during a flood. Changes in active channel widths since 1939 might signal a change in the stability of the river system, because channel widening is one way that the channel can compensate for excessive changes in flow or sediment supply. For the entire study area, the active channel widths have ranged between 150 and 800 feet. The present active channels in the four upstream reaches, where the channels are relatively straight and braided, are wider than the active channels in the four downstream reaches, where the channels are more meandering. Although the active channel widths vary from year to year, there are no significant long-term trends in active channel widths between the reaches or within a single reach over time.

6.3 Channel Slopes

The slope of the river generally decreases in the downstream direction throughout the study area. The slope in the Park reaches has been fairly consistent since 1939. In the meandering reaches, the slope is more variable and is mostly a function of where the channel is in its meander migration cycle. The Morgan's Crossing and Willoughby Creek Reaches were steeper in 1939 (0.0032 and 0.0028, respectively) than they were in 2002 (0.0028 and 0.0026, respectively). This is likely due to the fact that both channels are reaching the maximum limit of their meander migration cycle and are currently ready for a meander cutoff.

6.4 Channel Migration Rates

Channel changes in the Park Reach have consistently been the fastest, because the channels are straighter and braided and shift locations more frequently. The frequent shifts in the braided channels do not signal instability in the Hoh River system, because all of these changes are occurring within the HCMZ as part of the natural dynamics of the river.

The rate of channel migration in the Huelsdonk-South Fork Reach has generally been faster than it has in the downstream Morgan's Crossing and Willoughby Creek Reaches. In the Morgan's Crossing and Willoughby Creek Reaches, the fastest rates of meander bend migration occurred between 1977 and 1981, when the 25-year flood was exceeded twice. The upstream-most meander bend in each of these reaches is currently running slightly upstream. It is expected both of these meanders will cut off in the near future, and start a new meander migration cycle. This occurs because the meander bend becomes so elongated that the slope is reduced and the ability of the channel to transport flow and sediment no longer matches the incoming supply. Likely flow paths for a future cut off are the existing side and overflow channels in these reaches. Based on the historical photography in the Morgan's Crossing and Willoughby Creek Reaches, a meander cut off has only occurred twice from the late 1890s to 2002.

6.5 Frequency of Channel Occupation and Vegetation Stability within the HCMZ

In the Twin Creek, Snider Creek, and Hoh Ranger Station Reaches, the middle section of the HCMZ has persistently been unvegetated channel that is repeatedly reworked by the river. Areas along the edge of the HCMZ have typically only had the active channel run against them once or twice over the period of aerial photography record. Consequently, vegetated floodplain is preserved almost solely along the edges of the HCMZ and very few stable vegetated areas occur near the middle of the HCMZ. This helps to limit the amount of erosion that occurs along the HCMZ boundary. However, even limited amounts of erosion can cause management issues for areas where the Park Road is very close to the HCMZ boundary.

In general, in the Huelsdonk-South Fork Reach, the Willoughby Creek Reach, and the upstream portion of the Morgan's Crossing Reach, the sinuous, relatively narrow unvegetated channel has occupied an area within the HCMZ only a few times. Areas that have been persistently unvegetated channel are small, discontinuous, and typically occur at meander bend crossings. The two downstream-most reaches have small areas of floodplain near the middle of the HCMZ that have been vegetated since at least 1939. These areas have resisted erosion even when the river has run against them. These areas create hard points in the river, and can limit the rates of channel migration. They may be stable in part due to old growth woody debris that is present on their surface, or because log jams or other geologic features underlie the surface and protect them from erosion. Some larger areas of vegetated floodplain have been persistent since 1939 along the boundaries of the HCMZ also. The persistence of these vegetated areas may be mostly due to the fact that the river has not run through them since at least 1939.

The assessment of channel characteristics suggests that differences exist in the reaches that influence the rate of channel changes and expansion of the HCMZ. However, the consistency over time suggests that the present patterns have been persistent for at least the last 63 years (1939 to 2002) and likely since at least the cadastral survey maps.

7.0 SEDIMENT IN THE HOH RIVER SYSTEM

The natural sediment load of the Hoh River consists of a range of sizes from rock flour to large cobbles. Fine- and coarse-sized sediment originating from surface runoff (Kennard, 1999), mass wasting along the valley walls (Parks, 1999; Logen et al, 1991), and erosion of banks along the HCMZ boundary has increased in the Middle Hoh since 1939. It can be assumed that these processes, at times, increases the amount of fine and coarse sediment delivered to the mainstem river. The number of mass wasting areas (Lyon, 2003) and HCMZ bank erosion rates is thought to have been fairly consistent in the Park Reach during this same time period.

The addition of fine sediment to the river system in the Middle Hoh Reach would increase the suspended sediment concentrations. While this would result in an increase in turbidity, it may be difficult to distinguish from the natural suspended sediment load in most areas. The majority of fine sediment added to the Hoh River would easily be transported downstream to the Pacific Ocean. In areas of slow velocity, such as on the floodplain and side channels, the fine sediment may be deposited, and thus, negatively impact aquatic habitat.

If the additions of coarse sediment to the Middle Hoh since 1939 were great enough to exceed the sediment transport capacity of the river, then the channel planforms would likely change from meandering to straight, or even to a braided pattern. These changes in planform would be visible on the historical aerial photographs. However, no significant long-term changes in channel planform were observed in any of the eight study reaches. To provide more verification for this observation the sediment transport capacity of the river was investigated at a reach-averaged scale to evaluate the potential for excessive long-term sediment aggradation or incision, which would lead to a change in channel planform.

Visual observations document that sand- to cobble-sized sediment are present throughout the Hoh River system, which indicates these sizes of sediment are transported during floods. The slope of the river does decrease in the downstream direction which can reduce sediment transport capacity. However, the discharge increases in the downstream direction which can result in an increase in sediment transport capacity. To further investigate the sediment transport capacity of the river, total and unit stream power were computed. Total stream power computations, reach averaged discharge multiplied by slope, for 1939 and 2002 conditions indicate that the relative transport capacity of the study reaches remains consistent, except in Spruce Canyon where it is slightly higher. This analysis indicates that the decrease in slope is generally balanced out by the increase in discharge throughout the study area having no impact on sediment transport capacity.

Unit stream power, velocity multiplied by slope, was also computed based on several assumptions of average channel characteristics for each reach. These computations did indicate that the sediment transport capacity of the river increases in the downstream direction both in 1939 and 2002 conditions. However, it is thought that the amount of large, stable woody debris in the Park Reach is more frequent than in the Middle Hoh, and this wood along with steeper riffles do not get as easily drowned out during floods. This results in pools upstream of these controls that may actually decrease the local velocities in these reaches. If this is true, the unit stream power for the Park Reach would decrease and actually be fairly in balance with the Middle Hoh, again with Spruce Canyon being the exception. Based on all of these indicator tools, it is believed that the sediment transport capacity of the Hoh River is likely in balance with the natural sediment supply in the watershed, and that there has been no significant, long-term erosion or deposition along the Hoh River in the study reach within the last century.

8.0 HISTORICAL CHANNEL MIGRATION ZONE BOUNDARY

The HCMZ determined in this study has a high level of confidence because it was developed using a series of historical aerial photography that represents a period between 84 to 111 years of documentation with the 2002 aerial photography as the most recent channel position documentation (Attachment 2). The HCMZ boundaries were developed at a reach-scale mapping level and were intended to provide a relative comparison of river characteristics for the four reaches within the Olympic National Park with those for the reaches outside of the Park, which have experienced more human intervention. Actual boundaries shown on the maps in Attachment 2 probably have an accuracy of about a line width at the scale shown. Not all areas were investigated in the field due to the length of the study reach. Additional field investigation should be done to determine the precise line position at a property-scale level if needed for future management decisions.

The HCMZ boundary in 1939 and 2002 was compared in order to assess the locations and amounts of expansion of the boundaries in the eight study reaches. The HCMZ boundaries have been more stable in the four upstream reaches, which are within Olympic National Park, than they have been in the four downstream reaches, which are outside of the Park. Expansion of the HCMZ since 1939 has totaled approximately 47 acres in Olympic National Park since 1939, and about 276 acres in the Middle Hoh since 1939. Spruce Canyon, which is bedrock controlled, and the Mount Tom Reach, which is constricted by coarse alluvial-fan deposits that are not easily eroded by the river, have not had any measurable erosion since 1939.

The differences in the amount of erosion of the HCMZ appear to be the result of a combination of factors: (1) differences in channel form and slope of the river, (2) an increase in discharge as tributary flow is added to the main channel, (3) differences in the characteristics of the HCMZ boundaries, and (4) differences in human activities within and outside of Olympic National Park.

In most of the Park Reach, the channel is relatively straight, steep, and has multiple paths along which sediment is repeatedly reworked. The area of constant reworking is near the middle of the HCMZ and erosion along the edges of the HCMZ is minimal. In a few areas within the Park and for three of the reaches in the Middle Hoh, the channel pattern is more meandering. Most of the erosion of the HCMZ boundaries has occurred along the outside of these meanders. In the Middle Hoh the channel tends to remain against the same HCMZ boundary for longer periods of time than in the more dynamic Park Reaches, which means more erosion can occur. In a few instances erosion has occurred when a meander is cutoff and the new channel flows directly into a terrace bank.

Discharge increases in the downstream direction, particularly downstream of the confluence with the South Fork. Higher discharges can result in higher velocities, and higher sediment and wood transport capacity, and subsequently higher erosion potential along the boundary of the HCMZ.

Properties of the banks that define the boundaries of the HCMZ vary along the study reach. Of the 11.3 miles of the HCMZ boundary that have experienced erosion since 1939, 94 percent was composed of alluvial or glacial material. Glacial banks are more prevalent outside Olympic National Park, but of the total area of the HCMZ that has eroded, 86 percent (278 acres) was composed of alluvium. Additionally, the glacial banks often erode by a combination of processes, not just river erosion. There are fewer drainages in the Middle Hoh Reach that can deliver alluvial-fan deposits that are coarse enough to limit HCMZ expansion. In contrast, coarse alluvial-fan deposits are common in the Park Reach. The susceptibility to erosion based on bank material composition may partially explain why a greater length and area of HCMZ bank has eroded outside Olympic National Park than within it.

Where there is less resistance along the outside of a meander bend in either the Middle Hoh or Park reaches, accelerated rates of erosion can occur. The main form of resistance is typically from large woody debris. Additionally, large cobbles that are eroded from the bank can align along the toe of the bank, where they have been observed to limit expansion of the HCMZ in the Park Reach. Herrera found that riparian areas with trees that have stem diameters (dbh) >21" erode more slowly than areas with smaller vegetation (written communication, 2004). The reaches in Olympic National Park have less discharge than the reaches downstream from the confluence with the South Fork River, which would mean shallower water depths during floods in which to float the large woody debris. This may indicate that it takes larger diameter trees in the Middle Hoh to remain stable and limit erosion along the HCMZ banks or to remain stable and limit migration rates within the HCMZ itself. The removal of riparian forest and large woody debris along the terraces in the Middle Hoh has reduced the amount of large woody debris that can be recruited to the channel, because old growth vegetation along the terrace banks of the HCMZ has been eliminated.

To try and determine what impact logging may have had on erosion rates in the Middle Hoh, areas of similar channel form in the Park were used where the differences in erosion rates can be mostly attributed to changes in flow, slope, or human disturbance, mainly logging activities. For 14 areas (4 in Park and 10 in Middle Hoh) where an alluvial bank was eroded along the outside of a single meandering channel bend, the average maximum erosion width over the entire study period between 1939 and 2002 was determined. The total stream power (2-year discharge multiplied by the average hydraulic slope) for each reach were then normalized and divided into a normalized erosion width so that a dimensionless total stream power factor could be applied to make the erosion areas more comparable. The computations show there is up to about 60% increase (maximum value) in erosion amounts in the Middle Hoh that can not be explained solely by a change in channel form, discharge, or slope. This provides some indication that logging of the terrace surfaces adjacent to the HCMZ has caused an additional amount of erosion in the Middle Hoh since 1939 that otherwise would not have occurred.

9.0 FUTURE HCMZ EXPANSION

The potential risk of additional lateral expansion along the HCMZ boundary was estimated to identify all of the areas along the HCMZ boundary that are likely to erode at some point in the future. The risk categories were subdivided based on the timeframe in which the river might be expected to run against them and cause erosion (Attachment 2). For example, actively eroding banks have the river running against them right now and may currently pose a threat to infrastructure or cause a loss of property during floods. Banks with a high risk are areas where the river is most likely to migrate or avulse to from its current position. Banks with a moderate risk may not see the river run against them until several years in the future, and could be considered to have a lower priority for management than the active and high risk banks. Banks with a low risk have not had the channel run against them since at least 1939 and this pattern is expected to continue in the future. The rates that each bank might erode while the river ran against it were also estimated. Finally, the maximum lateral extent of future expansion of the HCMZ over the next few centuries was also delineated and is referred to as the future CMZ (Attachment 2).

The likelihood of future erosion along the HCMZ boundary is based on (1) the likelihood the channel will run against the boundary and the erodibility potential of the boundary. Potential rates of lateral erosion of the HCMZ boundary in the near future also were estimated using (1) the erosion rates of similar type banks observed between 1939 and 2002, (2) the existing properties of the HCMZ boundary and (3) the vegetation and land use along the boundary and adjacent surfaces.

The maximum lateral extent of potential future erosion areas along the HCMZ was also delineated and is referred to as the future CMZ (Attachment 2). The time frame chosen for the future CMZ is approximately the next few centuries. In estimating the future CMZ we made the following assumptions: (1) the present land use within the Hoh River valley and within the HCMZ will not substantially change, and (2) the climate and coarse sediment supply to the river will not substantially change. It should be noted that roads and areas of the HCMZ that are currently armored were assumed to be subject to future erosion. In reality, these areas may be maintained and protected from erosion in the future and limit expansion of HCMZ relative to what is shown in Attachment 2. The maximum lateral extent of future erosion is generally greater outside of Olympic National Park, largely because there is not much to limit or slow the rate of erosion outside the park except for a change in river position.

The locations and rates of erosion of the HMCZ boundaries between 1939 and 2002 were used to estimate where and how much future erosion might occur along the HCMZ boundary over the next few centuries. No future erosion was allowed in areas where the present HCMZ boundary is restricted, such as by bedrock or a historically persistent stable bank. The future CMZ includes all areas that have the potential to erode over the next few centuries. However, erosion to the boundaries of the entire future CMZ is not expected during that time frame. Which areas that will actually erode depend upon the alignment of the river channel and the length of time it is against the HCMZ boundary.

Overall, the HCMZ boundaries both within Olympic National Park and outside of the Park have several areas that are actively eroding or have a high likelihood for future erosion. However, the rates of future erosion for boundaries within the Park are estimated to generally be much slower than those for boundaries outside of the Park. The confidence in the future CMZ boundary is less than that of the HCMZ boundary, and risk assessment categories for several reasons. The assumption had to be made that land use, hydrology, and sediment loads would not markedly change in the future in such a way that past rates of erosion would no longer be applicable to future rates. Historically, logging has been limited in the Park but has been very extensive in the Middle Hoh. Any changes in land use could impact future rates of erosion. Flood peaks and flood magnitudes have been higher in recent decades than they were in the earlier part of the century, and it is not known how this apparent trend may impact future channel migration rates. Increases in sediment load since 1939 have not appeared to influence the channel form, however if this changed it could impact future rates of HCMZ expansion. Also, additional terrace boundaries between the valley wall and the HCMZ boundary likely exist but have not yet been identified, particularly in the Park Reach. These terraces could act as natural limitations on HCMZ expansion at locations other than what was delineated. This type of information could be gathered through additional field work or with data collection techniques that can penetrate dense vegetation such as light detection and radar data (Lidar).

10.0 AQUATIC HABITAT CONSIDERATIONS WITHIN THE HCMZ

Although more assessment would need to be done to integrate habitat localities into this analysis, some generalized conclusions regarding aquatic habitat in relation to river processes are provided. Current analysis suggests that increased fine sediment loads (above natural levels) likely occur in the Middle Hoh Reaches due to accelerated mass wasting (Parks, 1999), surface erosion (Powell, 1999) and bank erosion rates measured in this study. This could result in temporary increases to turbidity during high flows, but may be difficult to detect given the naturally high suspended-sediment levels in the Hoh River. Additionally, this increased fine sediment load may result in higher volumes of sediment deposited in slow-velocity areas during the recession of floods. Areas that could be most impacted would include side and overflow channels, where the channel bed could become plugged with fine sediment and limit the groundwater interaction between these areas and the main channel.

Natural channel form and wood may also play a role in the type of aquatic habitat available. The meandering channels in the Morgan's Crossing and Willoughby Creek Reaches result in large, long-term stable side channels, which are not present along the straighter channels in the upstream reaches. The upstream reaches do include several overflow channels, but these are typically inundated only during high flows. However, habitat is enhanced in the upstream reaches by the greater amount of wood that is present relative to the total active channel area. The wood creates complex habitat and small backwater pools, which are not present in the downstream Middle Hoh Reaches.

Both reaches have significant tributary streams that connect to the Hoh River and provide additional habitat and water to side channels within the HCMZ. Tributaries in the Park reaches have not been impacted by logging on the hillslopes, but often have been impacted by road crossings that are inadequate to pass natural sediment loads. During rainstorms, these sediment loads can plug the road crossing and impact the channel form and hydraulics. Tributaries in the Middle Hoh Reaches can also be impacted by road crossings and additionally have several areas of mass wasting that have impacted the rate and amount of debris flows that reach the Hoh River, according to reports in the Middle Hoh watershed analysis and a report on Huelsdonk Ridge (Parks, 1999; Powell, 1999; Logan et al, 1991).

11.0 SUMMARY OF POTENTIAL INFRASTRUCTURE CONCERNS

Of the 6 miles of Park Road, 0.9 miles (15 percent) of the Park Road is protected by riprap, which armors the adjacent river bank. Approximately 0.24 miles of the river bank armoring is located along portions of the road that coincide with the HCMZ boundary at Road Mile 0.8 and 2.2. In these areas the bank armoring does not limit the channel from migrating to where it has historically been. However, relative to the forested river bank, the riprap does not provide the same roughness, cover and potential recruitment of woody debris that the natural bank would. The remaining 0.64 miles of armored river bank along the road are located on alluvial banks that are within the HCMZ at the Park Boundary and near Taft Creek. Additionally, two areas of road at MP 1.5 and 1.7 have experienced active erosion, but these sections of road were setback to the valley wall rather than armoring the bank.

There are 3 additional locations along the Park Road that were identified to be at risk in the near future that total 0.4 road miles:

1. 500 ft of bank immediately downstream from the existing bank protection at MP 0.8;
2. 1,250 feet of eroding bank along 680 feet of road near MP 3.0;
3. 1,900 feet of eroding river bank along 850 feet of road downstream of Taft Creek near MP 5.5

During the October 2003 flood, an approximately 150-foot section of the Park Road near MP 5 was eroded by the river. Areas that have been armored may be eroded again in the future and require some additional management actions, but the setback areas are not likely to require additional interaction unless river erosion becomes accelerated beyond historical rates which is not expected. The remaining 4.7 miles of road are set back far enough from the river that erosion is not likely. Together, the previously armored sections of river bank and the potential future erosion sections amounts to 22 percent of the total Park Road that either have required management action or may require action in the future.

Of the 12 miles of County Road, 5 areas totaling 1.2 miles (10 percent) of right HCMZ boundary have been armored. Additionally, a landslide area near Road MP 9.7 endangers the road. There are landslide areas within glacial materials on the left HCMZ that will continue to contribute sediment to the river as long as the river runs against them. Future river bank erosion is likely at Lewis Ranch and Huelsdonk Ranch, and along the County Road between MP 5 and 6. During the October 2003 flood it was relayed by Park Service personnel that a portion of the upstream end of Lewis Ranch where armoring had been placed was eroded and had to be repaired. This particular location had armoring that extended along the outside of a meander bend and limited migration of the river channel.

Debris flows from tributary streams can cause damage to roads and private property. Debris flows on tributary channels do occur naturally, but they can also be initiated by logging activities. Many of the tributaries have experienced incision and a loss of woody debris as a result of debris flows, which have also destroyed fish habitat (Kennard, 1999; Hatten, 1991). Additionally, mass wasting on hillslopes is thought to increase the volume of debris flows relative to natural levels that occurred historically (Logan et al, 1991). Even in Olympic National Park where debris flows are a naturally occurring process, they can deposit at road crossings where the slope flattens out or where there are undersized drainage crossings causing the road to be flooded and sometimes become impassable.

12.0 POTENTIAL STRATEGIES FOR EXISTING AND FUTURE EROSION AREAS ALONG HCMZ

If it is desired to mitigate for the impacts of existing riprap on aquatic habitat, one possible strategy would be to install engineered log jams along the riprap to deflect the river away from the bank and encourage sediment deposition in the eddy downstream of the log jam. The gravel bar formed downstream of the logjam can grow vegetation and provide a more natural buffer between the river and riprap. In addition to providing some habitat restoration, this would also provide additional protection against bank erosion and reduce the risk of future erosion. Construction of the log jam would have relatively little risk in endangering the protected road or property because even if the log jam were to wash out, they would still be protected by riprap.

One of the best ways of protecting the road from stream bank erosion is to align the road on a terrace farther away from the river near the valley wall. Care must be taken to insure that the road is not so close to the valley wall that landslides become a hazard to the road. However, the road cannot always be setback and stream bank protection is sometimes required. Riprap can be an effective material to prevent bank erosion if properly designed, but it also prevents or limits riparian forest vegetation from growing along the banks. Riparian forests provide a root structure to the stream bank and a potential source of large woody debris during future bank erosion. This impact of riprap can be reduced by building a rough and irregular alignment to the bank protection, which will create eddy and sediment deposition zones. These sediment deposition zones will eventually support riparian vegetation. Stream bank erosion often occurs along the outside of a meander bend. If riprap is placed along a smooth curvilinear alignment, then it will tend to lock the position of the meander bend and channel thalweg in place and prevent its migration downstream. The construction of a rough and irregular alignment of bank protection will also help to avoid locking the meander bend and channel thalweg in place. The constructed bank protection should be irregular enough to create eddies and sediment deposition zones, but the bank protection should not cause the river channel to abruptly change course in a tight radius of curvature. Such a design will likely fail.

There are two areas of armored banks located within the HCMZ. At the Park Boundary, the road crosses an old meander bend near the valley wall. This segment of road is armored with riprap. Although this bank armoring has limited the lateral migration of the river channel, it has not caused the river to follow any course that it had not previously followed during the past century. The road cannot be setback at this location because of the landslide hazard that was experienced back in 1960 when a setback was implemented. At the Rainforest Campground, a large portion of the armored bank is within the HCMZ and this does constrict the channel and impact river processes. This activity may have increased the extent of erosion on the opposite left HCMZ boundary, but there is no infrastructure or human use of the left terrace. Management will need to evaluate whether to continue to maintain the Taft Pond, which was created by the road because it acts like a dam to Taft Creek. Presently, Taft Creek passes under the road through a culvert and then though a rock fish ladder to the Hoh

River. Although this pond is not natural, it may provide certain aquatic habitats and aesthetic values.

Boundaries of the HCMZ that have a high risk of future erosion should be monitored where infrastructure or property could be damaged. Bank protection that is constructed prior to severe erosion could be done with less impact than bank protection that is constructed on an emergency basis and can incorporate habitat restoration goals where appropriate. Perhaps the biggest benefit to constructing the protection ahead of severe bank erosion is the ability to work under relatively dry conditions. Under such conditions, it would be easier to integrate features that enhance natural habitat such as engineered log jams into to the bank protection design.

Alluvial terrace banks along the HCMZ boundary where trees have been cleared would benefit from a long-term strategy of planting native trees that can one day grow to an old growth forest. While large trees would take several decades to become established, over the long-term, they would help slow the rates of terrace bank erosion along the HCMZ boundary and provide a potential source of large woody debris. Although trees could help stabilize surface erosion on glacial banks, most glacial banks are much taller than the root structure of trees, so the root structure would not help to prevent erosion at the river level. However, large old growth trees that fall into the river during bank erosion may help to deflect the river velocities away from the toe of the eroding bank.

Landslide areas along the river may be impacted by stream bank erosion at the toe of the landslide. In many cases, groundwater flow encountering an impermeable layer on a steep slope is the primary cause of the landslide. Engineered drainage paths, stabilization of the toe of the landslide, or structures that deflect the river away from the landslide may help limit additional erosion.

Areas impacted by tributary debris flows may have different management approaches depending on what structures or property are at risk, such as a road or residents living on a debris fan.. Where there is only a road crossing, bridges or box culverts with metal grates at the road surface could be installed. Debris could be cleaned from the box culverts after a debris flow by opening the grates on the road surface. These types of crossings provide an easy way to clean out the channel after debris flows and limit the potential for the road being shut down due to plugging. In areas where there are residential properties, sediment from the debris flows and flood runoff can both be a continuing problem. In some cases, the occurrence and frequency of debris flows has been exacerbated by logging and the associated road building activities. This type of disturbance can take several decades to re-establish hillslope stability even if no further logging is done. People and their structures may have to be relocated off the debris fan to avoid the potential hazards. This report focuses on processes of the mainstem river channel and additional study would be needed to address the hazards caused by debris flows.

13.0 REFERENCES

See reference section in main report for full list of literature utilized in this study.

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ATTACHMENT 1: PHOTOGRAPHIC OVERVIEW OF THE HOH RIVER AND SOUTH FORK DRAINAGES

The study reach discussed in this report extends between RM 17 and RM 40 on the Hoh River, but photographs are provided in this attachment from a helicopter reconnaissance of the entire watershed including the South Fork drainage which is the largest tributary to the Hoh River. These photographs are presented to give the reader an overview of the different river characteristics present within the Hoh River watershed. The photographs are viewed looking upstream and are labeled by River Mile (RM). River miles are designated by the distance upstream from the mouth of the Hoh River and increase in the upstream direction (RM 0 is located at the mouth).

Hoh River Overview Photographs From October 2000 Helicopter Flight

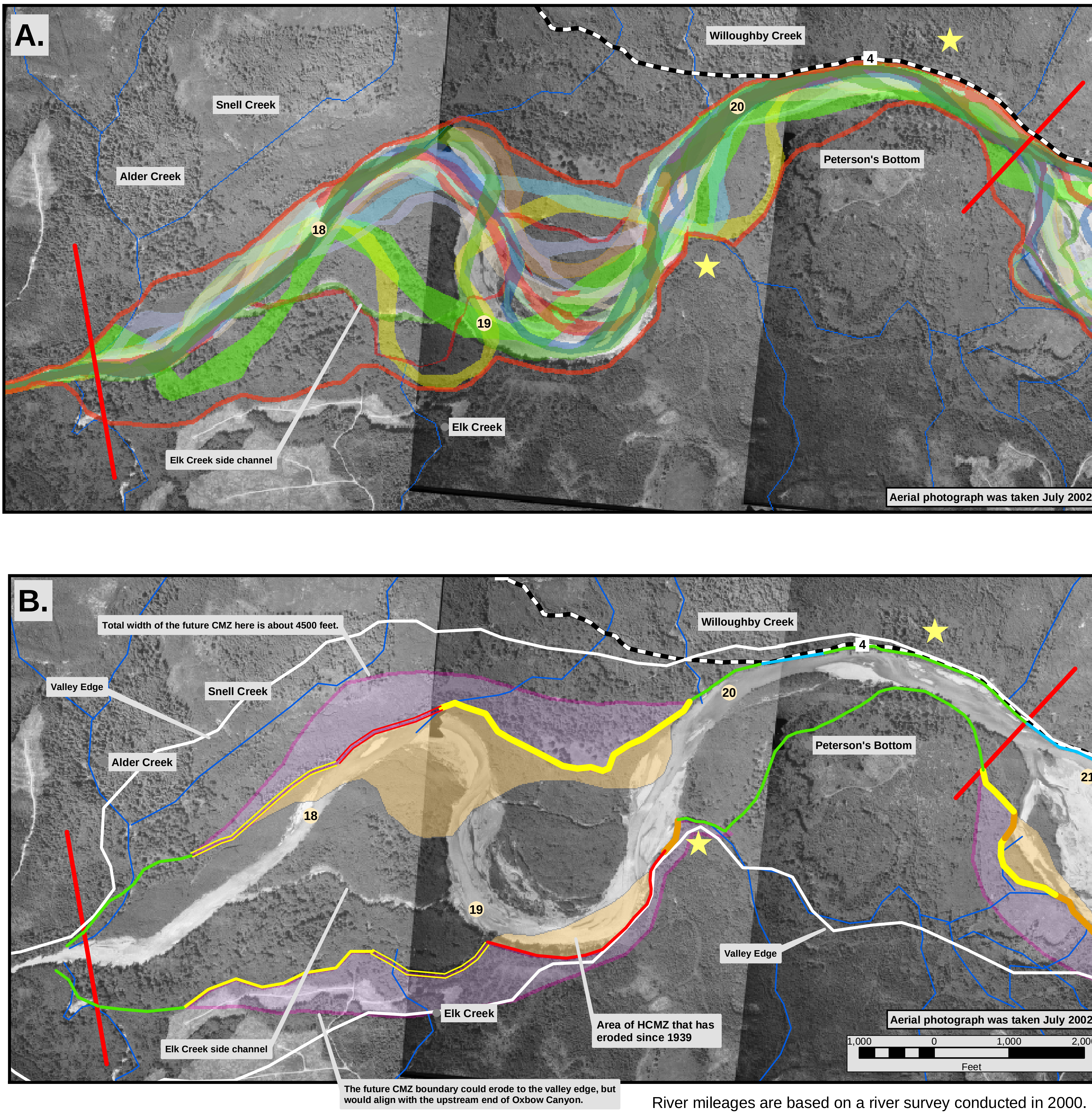
Hoh River Overview Photographs From October 2000 Helicopter Flight

Hoh River Overview Photographs From October 2000 Helicopter Flight

South Fork Hoh Overview Photographs From October 2000 Helicopter Flight

ATTACHMENT 2: MAPPING OF HISTORICAL LOW-FLOW CHANNELS, THE RISK AND RATE OF EROSION ALONG THE HCMZ, AND THE FUTURE CMZ

This attachment provides a summary by reach of the historical low-flow channel paths since 1939, the 2002 HCMZ boundary, the risk of expansion of the HCMZ boundary in the next several years, and the potential limits of expansion (future CMZ) over the next few centuries. A legend is provided on each figure to help the reader interpret each boundary. It is important to note that the future CMZ represents all areas that have the potential to expand, but does not mean that the total area between the 2002 HCMZ and future CMZ would necessarily erode in this timeframe. The exact areas of erosion will depend on the future position of the river.



River mileages are based on a river survey conducted in 2000.

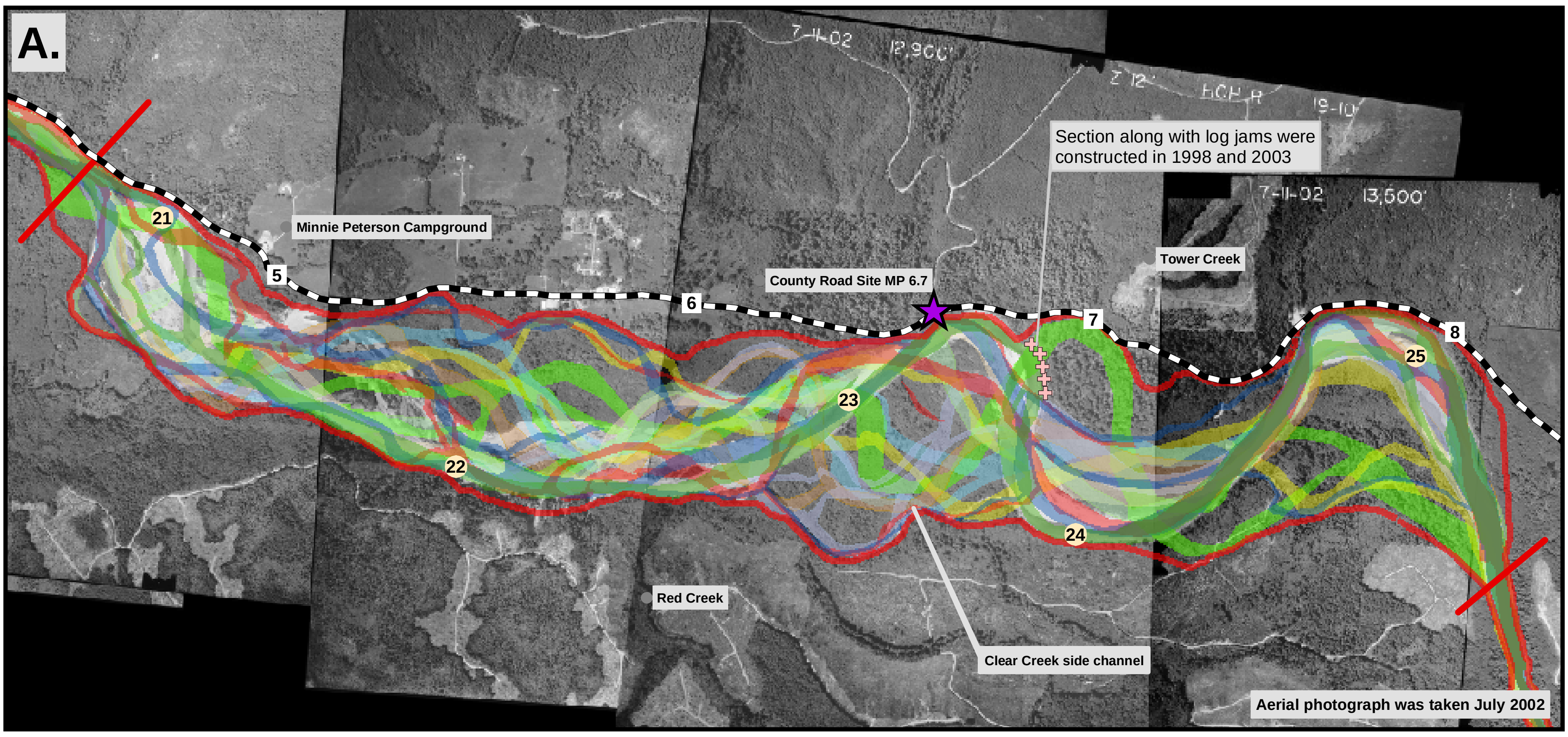
A. Low-flow channels

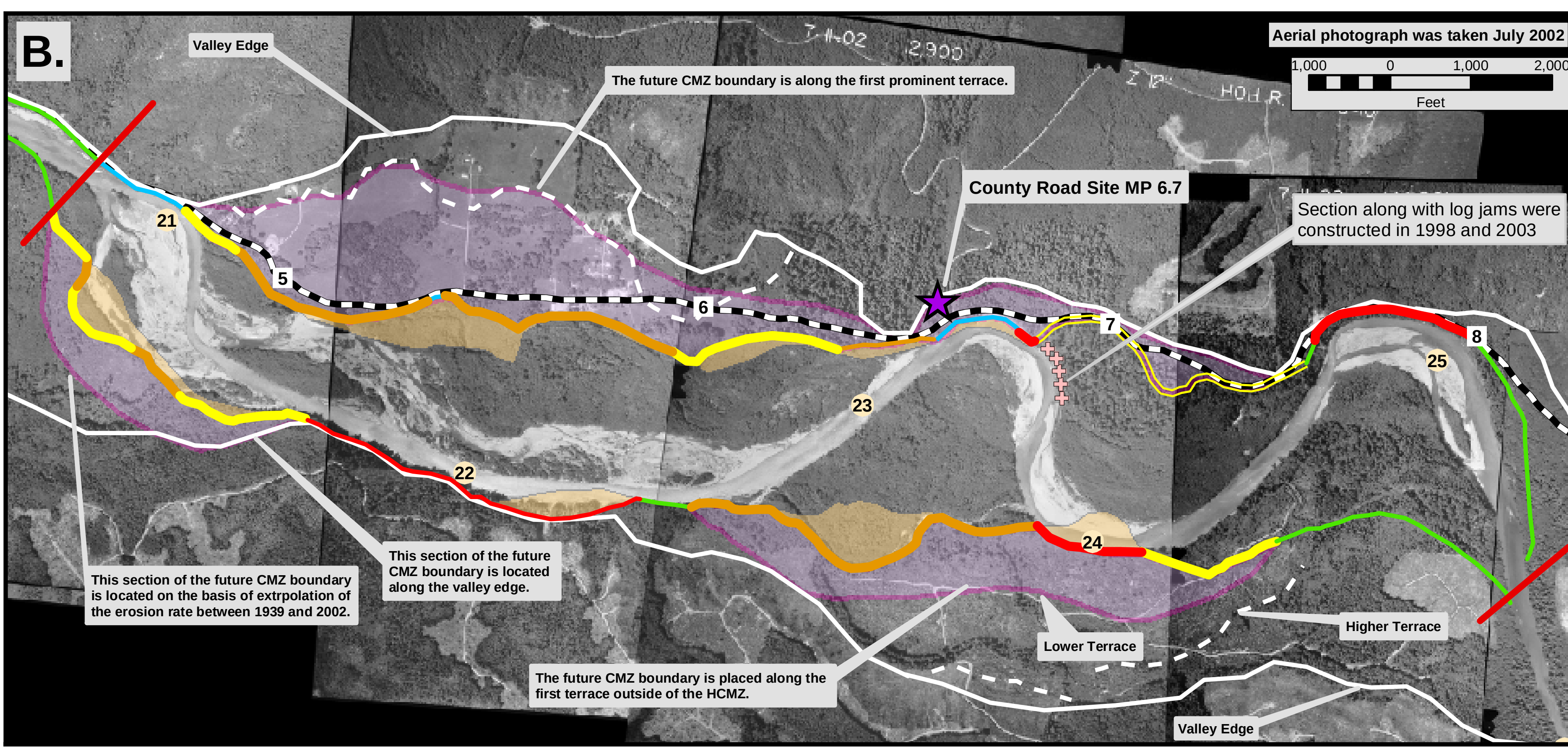
- 2001 Channel
- 1994 Channel
- 1987 Channel
- 1981 Channel
- 1977 Channel
- 1971 Channel
- 1960 Channel
- 1950 Channel
- 1939 Channel
- 1891/1895 Channel
- HCMZ boundary
- Reach Boundaries
- Jefferson County Road
- County Road Mile Post
- River Miles

B. Risk and rates of erosion along HCMZ boundary and future CMZ boundary

- Active_fast
- Active_medium
- Active_slow
- High_fast
- High_medium
- High_slow
- Low
- Armored
- Moderate_fast
- Moderate_medium
- Moderate_slow
- Very low
- Area Eroded 1939 to 2002
- Area of Possible Future Erosion
- Valley Edge
- Reach Boundaries
- Jefferson County Road
- County Road Mile Post
- River Miles
- Area that has been resistant to erosion since at least 1939

Figure 2.1. Historical channel position, risk assessment, and future channel migration zone boundary for the Willoughby Creek Reach.
A. Historical channel position between 1891 or 1895 and 2001.
B. The risk and rates of erosion are shown along the boundary of the historical channel migration zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If roads and protected banks are maintained, then they would be the limits of lateral erosion along the HCMZ boundary.





River mileages are based on a river survey conducted in 2000.

A. Low-flow channels

- 2001 Channel
- 1994 Channel
- 1987 Channel
- 1981 Channel
- 1977 Channel
- 1971 Channel
- 1960 Channel
- 1950 Channel
- 1939 Channel
- 1895 Channel
- HCMZ boundary
- Reach Boundaries
- County Road Mile Post
- Jefferson County Road
- River Miles
- Constructed Log Jams

B. Risk and rates of erosion along HCMZ boundary and future CMZ boundary

- Active_fast
- Active_medium
- Active_slow
- High_fast
- High_medium
- High_slow
- Low
- Armored
- Moderate_fast
- Moderate_medium
- Moderate_slow
- Very low
- Area Eroded 1939 to 2002
- Area of Possible Future Erosion
- Terraces
- Valley Edge
- Reach Boundaries
- Jefferson County Road
- County Road Mile Post
- River Miles
- Constructed Log Jams

Figure 2.2. Historical channel positon, risk assessment, and future channel migration zone boundary for the Morgans Crossing Reach.
A. Historical channel position between 1895 and 2001.
B. The risk and rates of erosion are shown along the boundary of the historical channel migration zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If roads and protected banks are maintained, then they would be the limits of lateral erosion along the HMCZ boundary.

Attachment 2. Figure 2.2

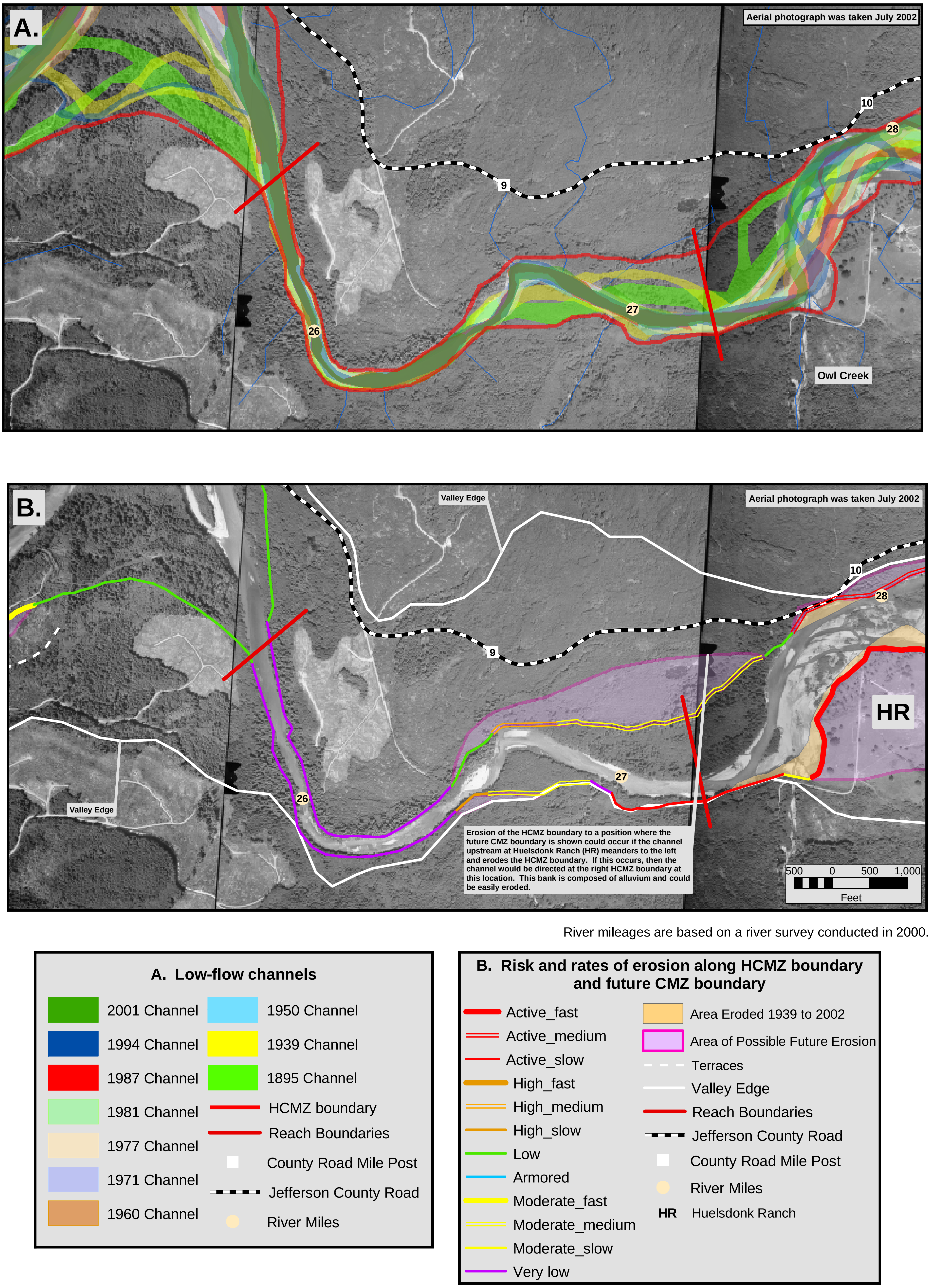


Figure 2.3. Historical channel position, risk assessment, and future channel migration zone boundary for the Spruce Canyon Reach.
A. Historical channel position between 1895 and 2001.
B. The risk and rates of erosion are shown along the boundary of the historical channel migtation zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If roads and protected banks are maintained, then they would be the limits of lateral erosion along the HCMZ boundary.

Attachment 2. Figure 2.3

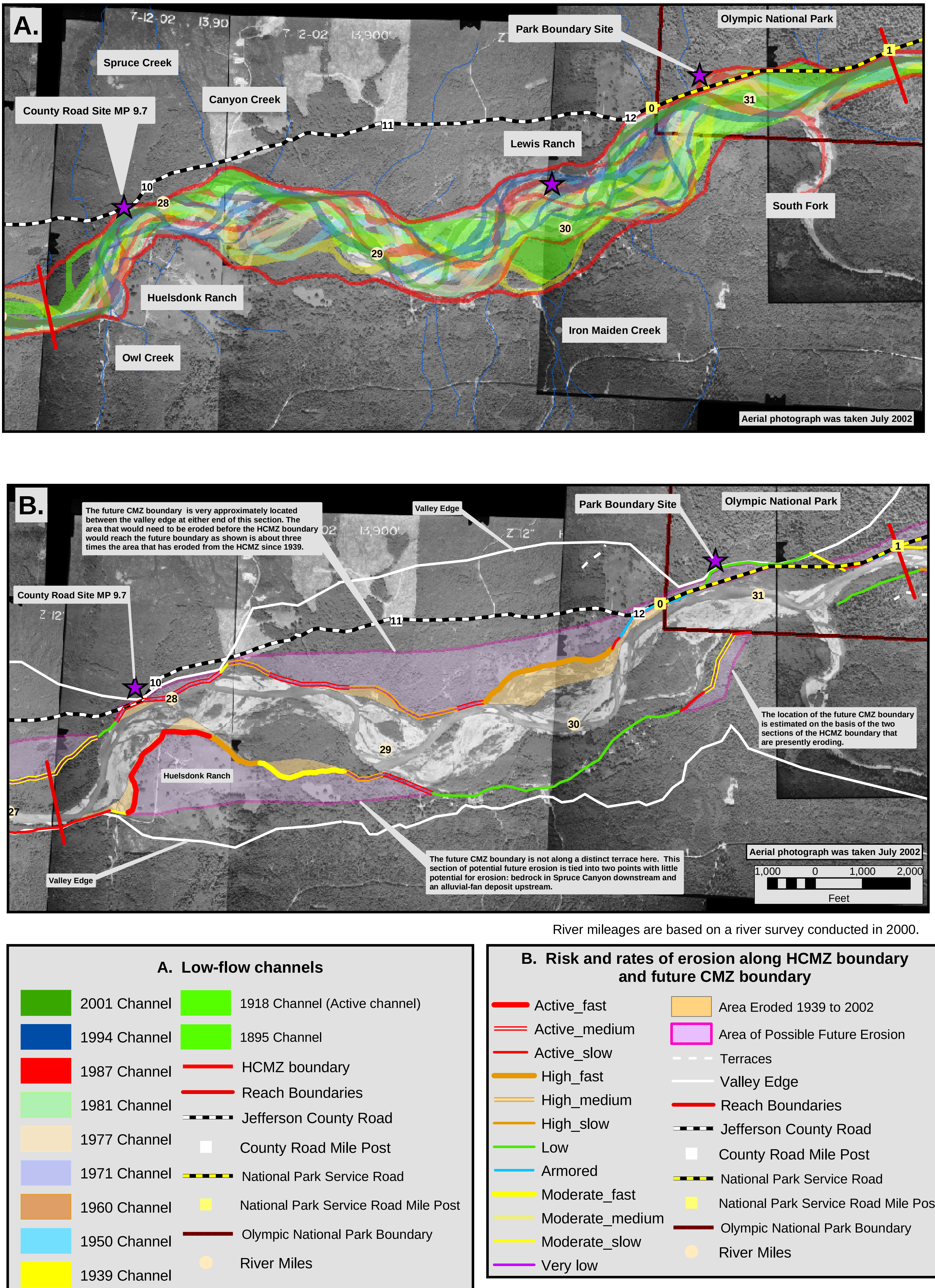
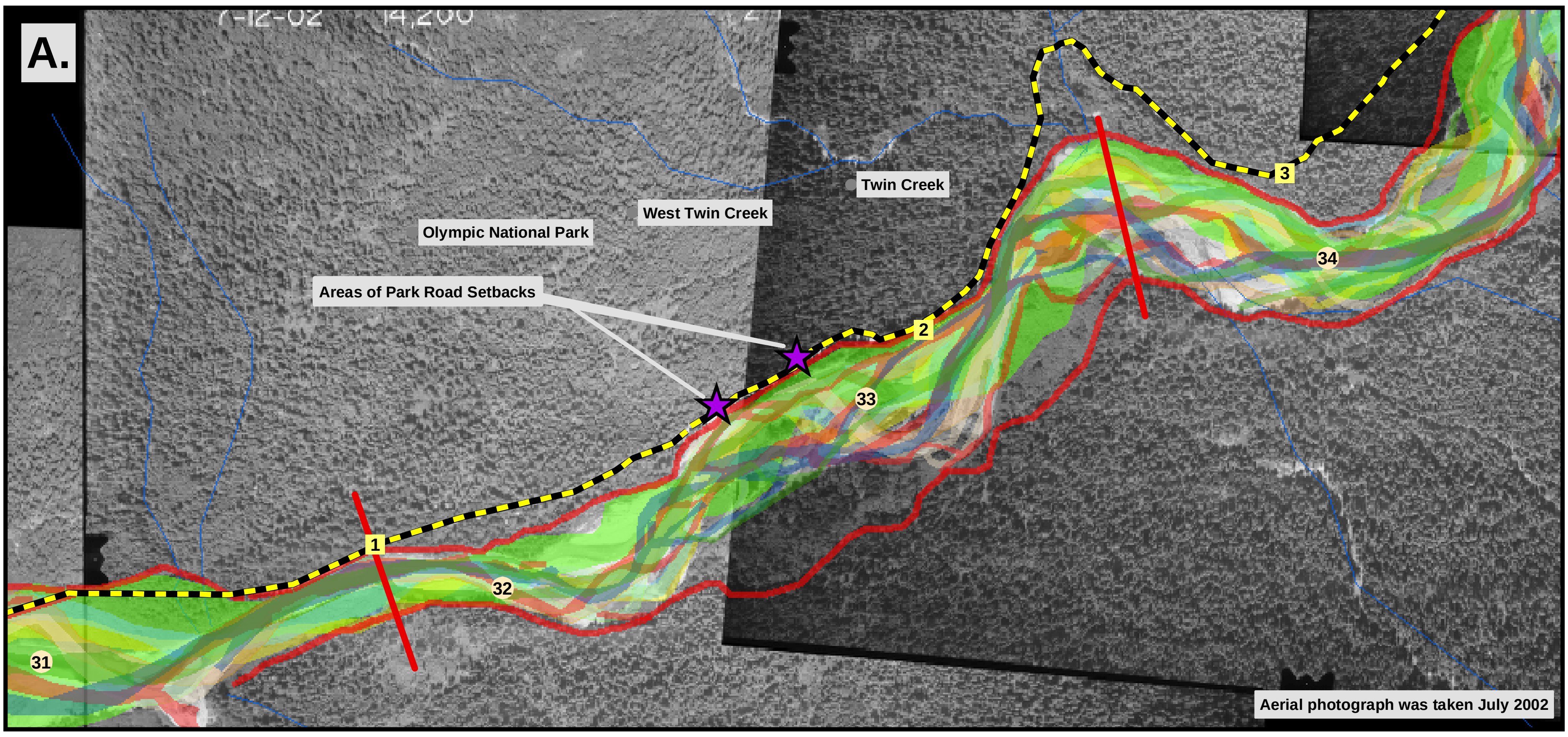
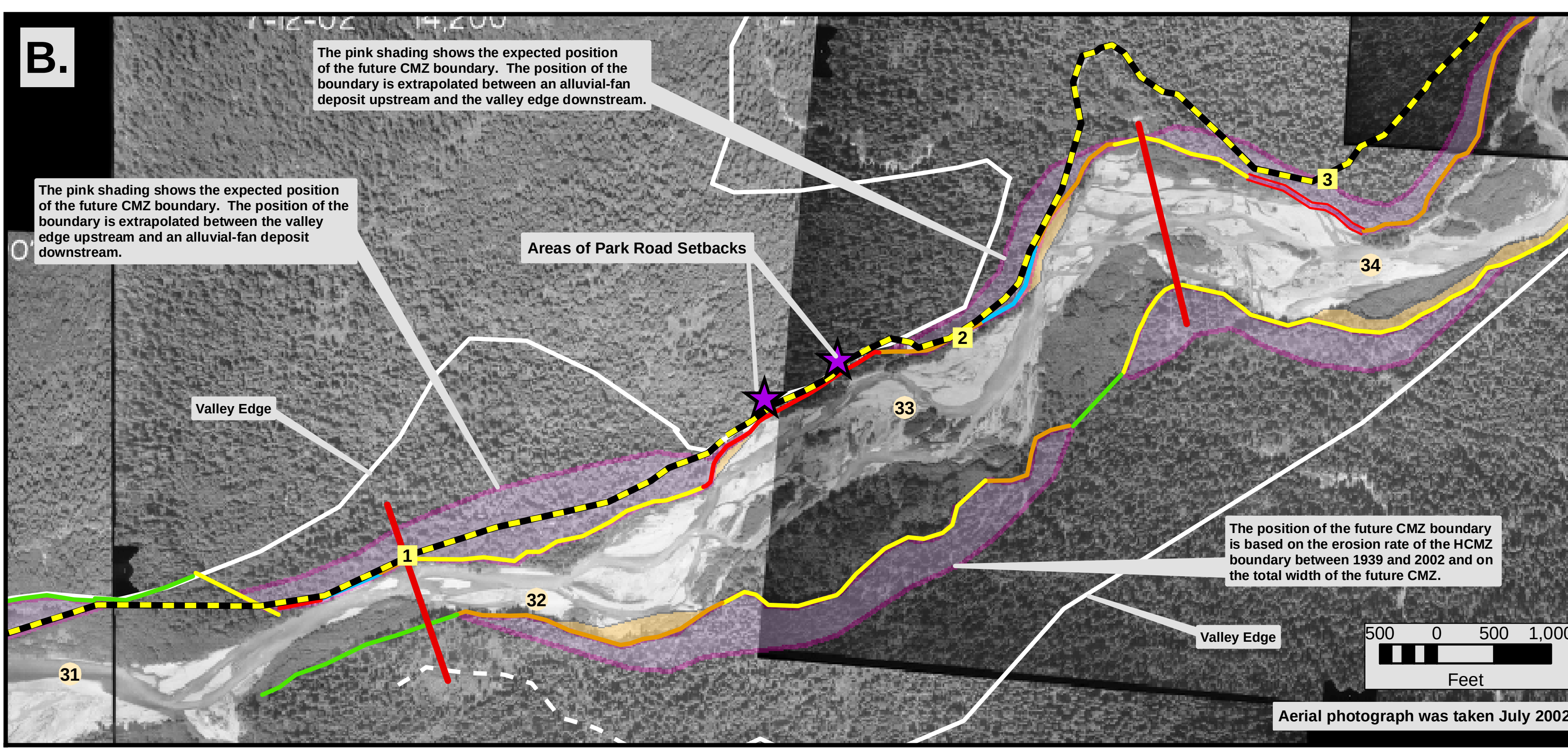


Figure 2.4. Historical channel position, risk assessment, and future channel migration zone boundary for the Huelsdonk-South Fork Reach.
A. Historical channel position between 1895 and 2001.
B. The risk and rates of erosion are shown along the boundary of the historical channel migration zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If road and protected banks are maintained, then they would be the limits of lateral erosion along the HCMZ boundary.

Attachment 2. Figure 2.4





River mileages are based on a river survey conducted in 2000.

A. Low-flow channels

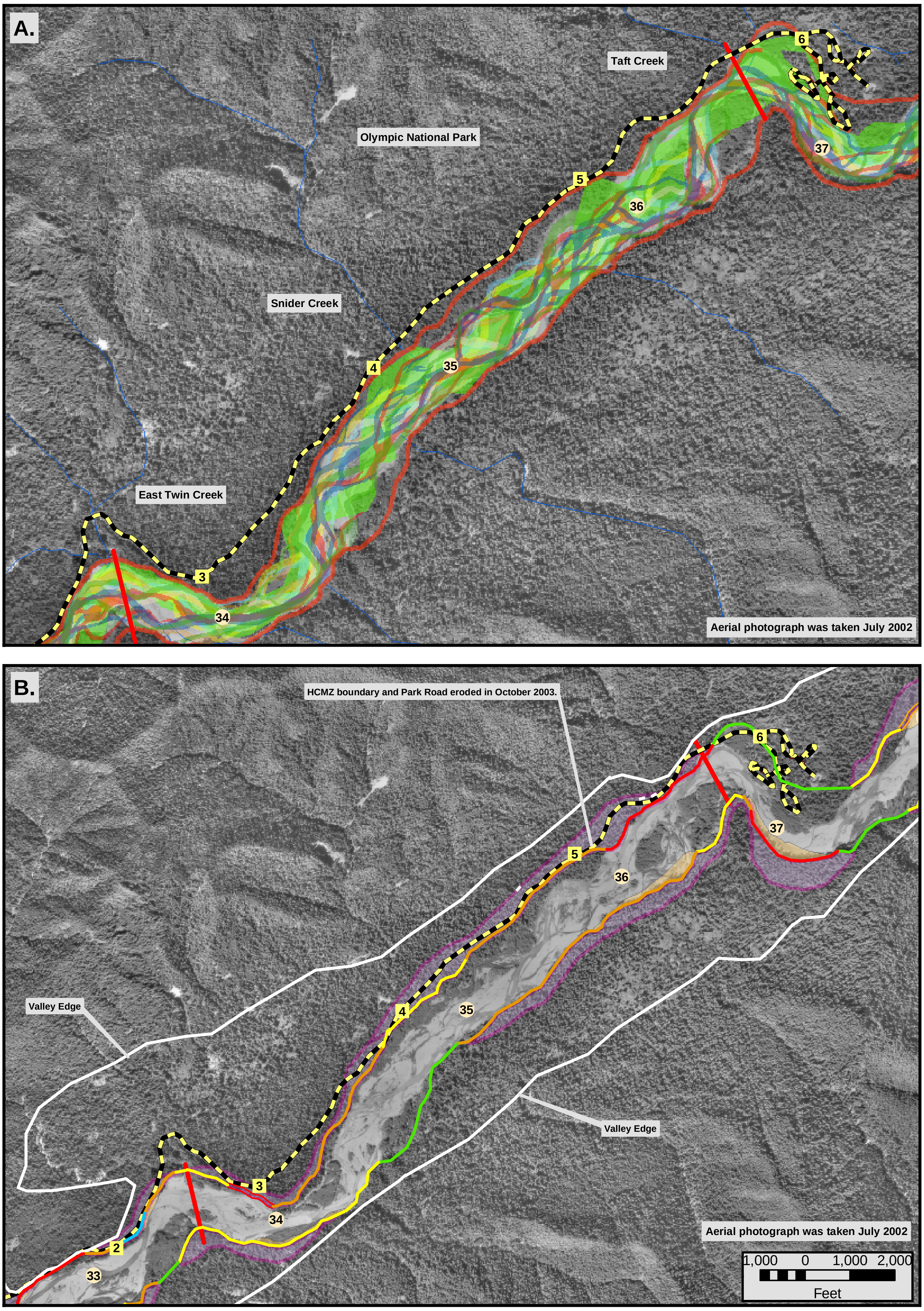
- 2001 Channel
- 1994 Channel
- 1987 Channel
- 1981 Channel
- 1977 Channel
- 1971 Channel
- 1960 Channel
- 1950 Channel
- 1939 Channel
- 1918 Channel (Active channel)
- HCMZ boundary
- Reach Boundaries
- National Park Service Road
- National Park Service Road Mile Post
- River Miles

B. Risk and rates of erosion along HCMZ boundary and future CMZ boundary

- Active_fast
- Active_medium
- Active_slow
- High_fast
- High_medium
- High_slow
- Low
- Low (armored)
- Moderate_fast
- Moderate_medium
- Moderate_slow
- Very low
- Area Eroded 1939 to 2002
- Area of Possible Future Erosion
- Terraces
- Valley Edge
- Reach Boundaries
- National Park Service Road
- National Park Service Road Mile Post
- River Miles

Figure 2.5. Historical channel position, risk assessment, and future channel migration zone boundary for the Twin Creek Reach.
A. Historical channel position between 1918 and 2001.
B. The risk and rates of erosion are shown along the boundary of the historical channel migration zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If roads and protected banks are maintained, then they would be the limits of lateral erosion along the HCMZ boundary.

Attachment 2. Figure 2.5



A. Low-flow channels

- 2001 Channel
- 1994 Channel
- 1987 Channel
- 1981 Channel
- 1977 Channel
- 1960 Channel
- 1950 Channel
- 1939 Channel
- 1918 Channel (Active channel)
- HCMZ boundary
- Reach Boundaries
- National Park Service Road
- National Park Service Road Mile Post
- River Miles

River mileages are based on a river survey conducted in 2000.

B. Risk and rates of erosion along HCMZ boundary and future CMZ boundary

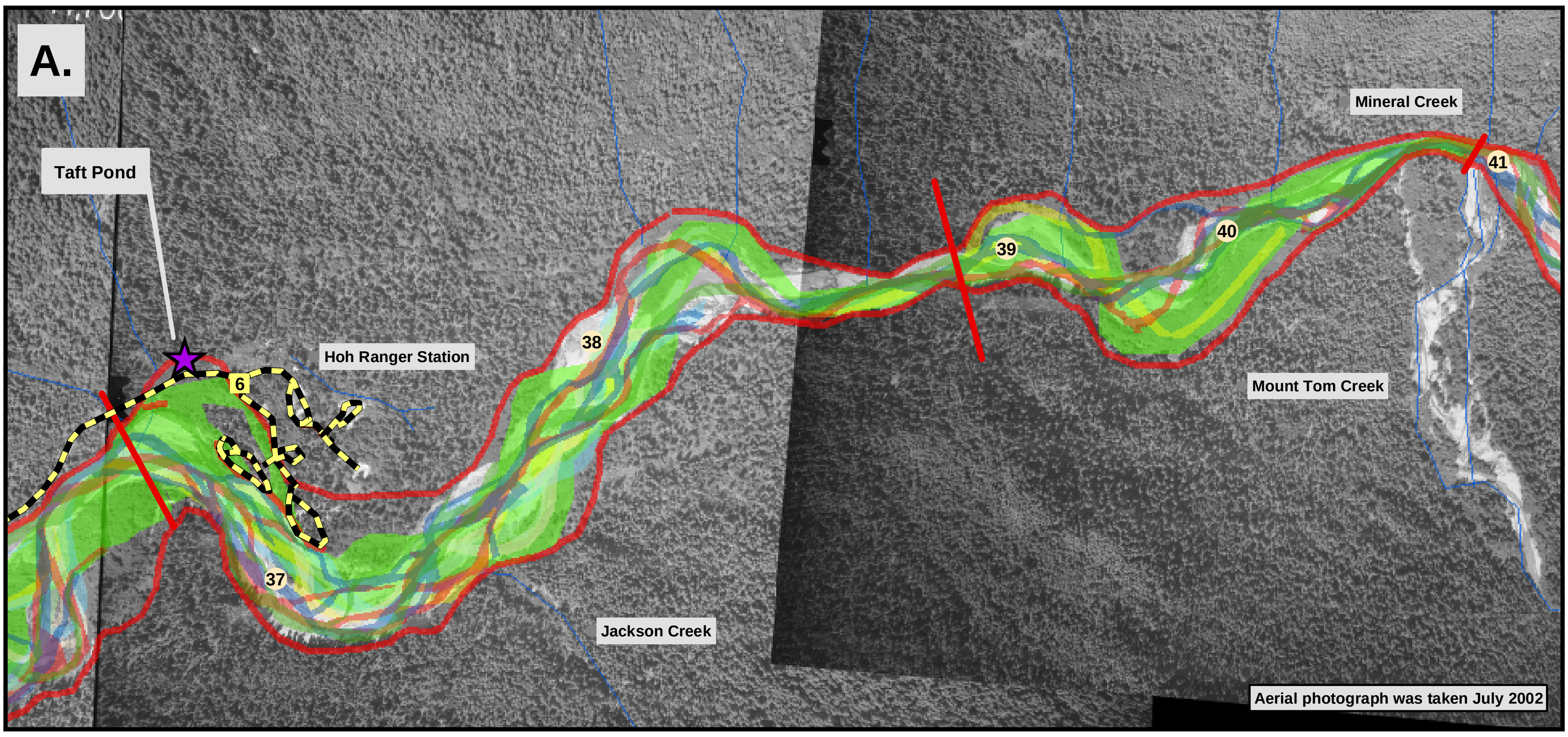
- Active_fast
- Active_medium
- Active_slow
- High_fast
- High_medium
- High_slow
- Low
- Armored
- Moderate_fast
- Moderate_medium
- Moderate_slow
- Very low
- Area Eroded 1939 to 2002
- Area of Possible Future Erosion
- Terraces
- Valley Edge
- Reach Boundaries
- National Park Service Road
- National Park Service Road Mile Post
- River Miles

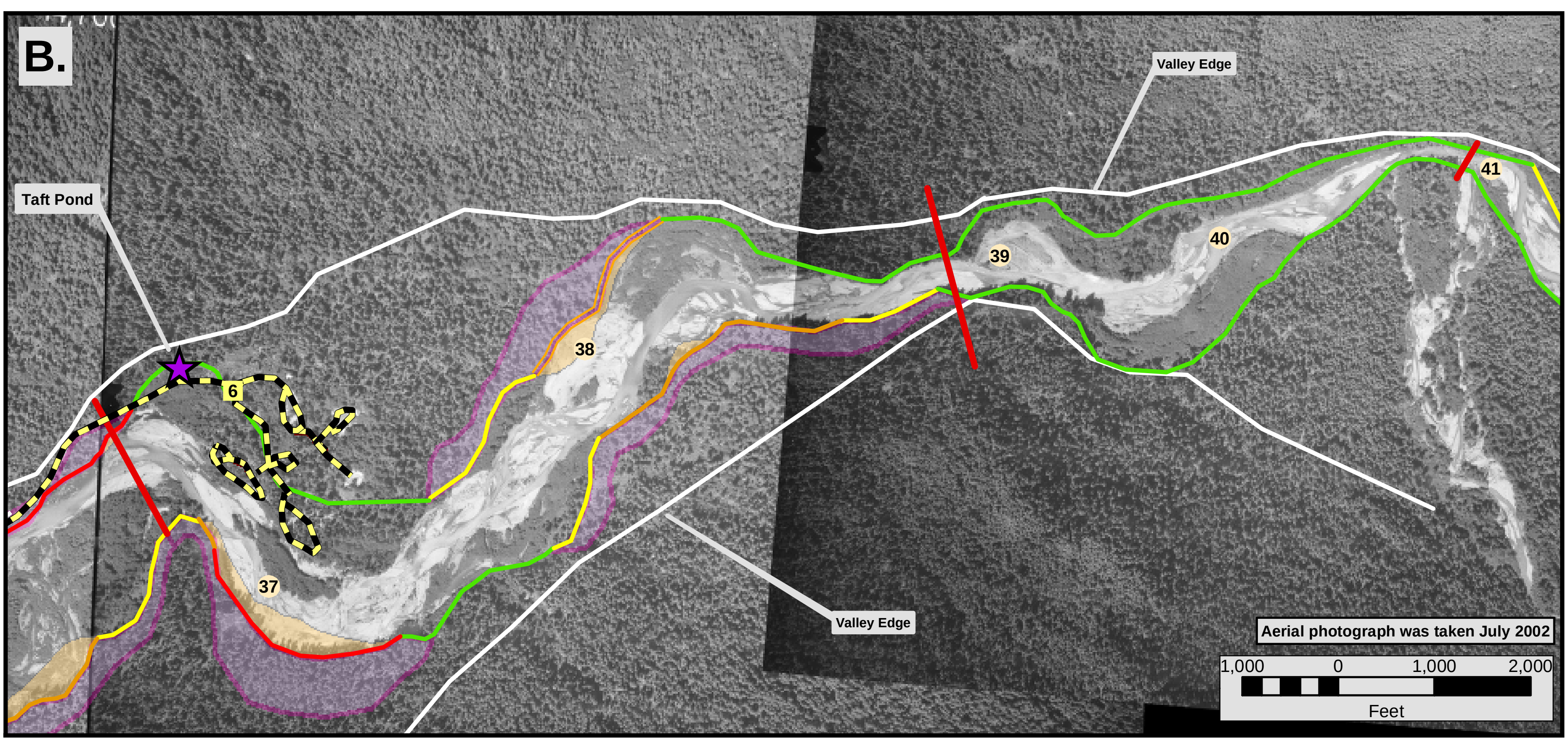
Figure 2.6. Historical channel position, risk assessment, and future channel migration zone for the Snider Creek Reach.

A. Historical channel position between 1918 and 2001.

B. The risk and rates of erosion are shown along the boundary of the historical channel migration zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If roads and protected banks are maintained, then they would be the limits of lateral erosion along the HCMZ boundary.

Attachment 2. Figure 2.6





River mileages are based on a river survey conducted in 2000.

A. Low-flow channels

- 2001 Channel
- 1994 Channel
- 1987 Channel
- 1981 Channel
- 1977 Channel
- 1971 Channel
- 1960 Channel
- 1950 Channel
- 1939 Channel
- 1918 Channel (Active channel)
- HCMZ boundary
- Reach Boundaries
- National Park Service Road
- National Park Service Road Mile Post
- River Miles

B. Risk and rates of erosion along HCMZ boundary and future CMZ boundary

- Active_fast
- Active_medium
- Active_slow
- High_fast
- High_medium
- High_slow
- Low
- Armored
- Moderate_fast
- Moderate_medium
- Moderate_slow
- Very low
- Eroded Area 1939 to 2002
- Area of Possible Future Erosion
- Terraces
- Valley Edge
- Reach Boundaries
- National Park Service Road
- National Park Service Road Mile Post
- River Miles

Figure 2.7. Historical channel position, risk assessment, and future channel migration zone boundary for the Hoh Ranger Station and Mount Tom Reaches.
A. Historical channel position between 1918 and 2001.
B. The risk and rates of erosion are shown along the boundary of the historical channel migration zone (HCMZ) by the line segments in varying colors and patterns. Areas of the HCMZ that we speculate could erode in the near future are shown in pink and define the boundary of a future channel migration zone. Sections of the HCMZ boundary that lack pink shading will likely be stable in the near future, and lateral erosion of the boundary is expected to be minimal in these areas. The pink-shaded areas show the maximum extent of expected lateral erosion assuming that no human structures exist. If roads and protected banks are maintained, then they would be the limits of lateral erosion along the HCMZ boundary.

Attachment 2. Figure 2.7